Supply Chain Performance Appraisement and Benchmarking for Manufacturing Industries: Emphasis on Traditional, Green, Flexible and Resilient Supply Chain along with Supplier Selection

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CERTIFICATE OF APPROVAL

Certified that the dissertation entitled **SUPPLY CHAIN PERFORMANCE APPRAISEMENT AND BENCHMARKING FOR MANUFACTURING INDUSTRIES: EMPHASIS ON TRADITIONAL, GREEN, FLEXIBLE AND RESILIENT SUPPLY CHAIN ALONG WITH SUPPLIER SELECTION** submitted by **Anoop Kumar Sahu** has been carried out under my supervision in fulfillment of the requirement for the award of the degree of ***Doctor of Philosophy*** in ***Mechanical Engineering*** at **National Institute of Technology**, **Rourkela**, and this work has not been submitted to any university/institute before for any academic degree/diploma.

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Abstract

Supply chain represents a network of interconnected activities starting from raw material extraction to delivery of the finished product to the end-user. The main constituents of supply chain are supplying/purchasing, inbound logistics, manufacturing, outbound logistics, marketing and sales. In recent times, the traditional supply chain construct is being modified to embrace various challenges of present business needs. Today's global market has become highly volatile; customers' expectations are ever-changing. Fierce competition amongst business sectors necessitates adapting modern supply chain management philosophies. Agility, greenness, flexibility as well as resilience have become the key success factors in satisfying global business needs. In order to remain competitive in the turbulent marketplace, industries should focus on improving overall performance of the supply chain network.

In this dissertation, supply chain performance assessment has been considered as a decision making problem involving various measures and metrics (performance indicators). Since most of the performance indices are subjective in nature; decision-making relies on active participation of a group of decision-makers (DMs). Subjective human judgment often bears some sort of ambiguity as well as vagueness in the decision making; to overcome uncertainty in decision making, adaptation of grey/fuzzy set theory seems to be fruitful.

To this end, present work deals with a variety of decision support tools to facilitate supply chain performance appraisement as well as benchmarking in fuzzy/grey context. Starting from the traditional supply chain, this work extends appraisement and benchmarking of green supply chain performance for a set of candidate case companies (under the same industry) operating under similar supply chain construct. Exploration of grey-MOORA, fuzzy-MOORA, IVFN-TOPSIS, fuzzy-grey relation method has been illustrated in this part of work.

Apart from aforementioned empirical studies, two real case studies have been reported in order to estimate a quantitative performance metric reflecting the extent of supply chain flexibility and resilience, respectively, in relation to the case company under consideration.

Performance benchmarking helps in identifying best practices in perspectives of supply chain networking; it can easily be transmitted to other industries. Organizations can follow their peers in order to improve overall performance of the supply chain.

Supplier selection is considered as an important aspect in supply chain management. Effective supplier selection must be a key strategic consideration towards improving supply chain performance. However, the task of supplier selection seems difficult due to subjectivity of supplier performance indices. Apart from considering traditional supplier selection criteria (cost, quality and service); global business scenario encourages emphasizing various issues like environmental performance (green concerns), resiliency etc. into evaluation and selection of an appropriate supplier. In this context, the present work also attempts to explore fuzzy based decision support systems towards evaluation and selection of potential suppliers in green supply chain as well as resilient supply chain, respectively. Fuzzy based Multi-Level Multi-Criteria Decision Making (MLMCDM) approach, fuzzy-TOPSIS and fuzzy-VIKOR have been utilized to facilitate the said decision making.

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CHAPTER 1

BACKGROUND AND RATIONALE

1.1 Introduction

A supply chain is a network of suppliers, manufacturers, and distributors through which raw materials are transformed into final products and delivered to the customers (Tavana et al., 2013). An important component in supply chain network design is the establishment of appropriate performance measures and metrics including qualitative and quantitative ones, where, for example, customer satisfaction, flexibility, and effective risk management etc. belong to qualitative performance measures, and cost minimization, fill rate maximization and so on belong to quantitative ones (Chen and Gong, 2013). Performance modelling and evaluation of supply chain networks are fundamental for supply chain network designs and optimization, thus, it has received much attention from academic researchers (Duri et al., 2000; Dong and Chen, 2005; Wu and Dong, 2008; Wu et al., 2012).

Supply chain performance evaluation problems are inherently complex problems with multi-layered internal linking activities and multiple entities. The supply chain performance measurement that only considers the initial inputs and the final outputs is generally inadequate since it ignores the internal linking activities among the suppliers, manufacturers, distributors, and customers. Performance improvement at an individual supply chain echelon does not lead to improvement in the supply chain as a whole. In order to measure supply chain performance effectively, it is necessary to consider the complex multi-layered internal linking activities between multiple entities (Tavana et al., 2013).

Recently market globalization has brought new challenges to the business owners. Market is continuously fragmenting, customers' demands are becoming uncertain to predict. In order to sustain in such a turbulent global marketplace, traditional supply chain management concept seems no longer effective. Supply chains need to be restructured to cope up with present business needs. In order to gain competitive advantage in the present market scenario; agility, flexibility, greenness as well as resiliency- these modern philosophies must be adapted.

During recent years, the natural environment has become a challenging topic that business organizations must consider due to the economic and ecological impacts and increasing awareness of environment protection. Green Supply Chain Management (GSCM) has emerged as an important organizational philosophy and a proactive approach to reduce environmental risks (Diabat et al., 2013).

Green supply chain management is a method to improve environmental performance. Under stakeholder pressures, forces and regulations, companies need to improve the GSCM practice, which are effected by practices such as green purchasing, green design, product recovery, and collaboration with patrons and suppliers. As companies promote the GSCM, their economic performance and environmental performance is expected to be enhanced. Hence, performance evaluation of green supply chain is very important for any company (Mirhedayatian et al., 2014). Reducing the environmental pollution from upstream to downstream during procuring raw materials, producing, distribution, selling products, and products depreciation is the most important goal of green supply chain management (Falatoonitoosi et al., 2013).

Apart from adapting 'greenness' in supply chain management, supply chain flexibility (SCF) has become another essential requirement in today's competitive market. According to the present scenario of unstable and fluctuating economy there is a corresponding change in the customer and market requirement, to be able to meet this corresponding change, organizations must be flexible enough to accommodate the given changes in an acceptable speed and cost.

Flexibility is required to satisfy unpredictable requirements and to enhance the competitiveness. The need for flexibility has gained the research interest in the present circumstances, and companies have recognized its importance and are looking forward to its implementation in various fields mainly operations systems, logistics process, supply network, organizational design and information systems (Chandrakar et al., 2012).

Supply chain flexibility (SCF) represents the ability of firms to respond to unanticipated changes in customer needs and competitor actions. Given the ever-changing turbulent market, resources that have historically sustained an organization's competitive advantage in business may no longer be viable. In today's world of globalization, competition has gone beyond the boundaries of single firms and extended across the full supply chain spectrum. It is, therefore, indeed essential that supply chain members adjust and reconfigure themselves to achieve a compatible balance between the responsiveness of their organizations and changes in the marketplace by increasing their flexibility in all operational activities. Supply chain flexibility involves the application of supply chain resources according to marketing dynamics, and requires firms to develop cross-functional and cross-company strategies that eliminate bottlenecks and create a level of performance that facilitates firms to strengthen their competitive advantage in an uncertain marketplace (Garavelli, 2003; Moon et al., 2012).

In the supply chain literature, the idea of resilience has recently been emerged, and is essentially defined as 'the ability of a system to return to its original state or move to a new, more desirable state after being disturbed' (Christopher and Peck 2004).

In particular, resilience has been used to examine responses to major supply chain disruptions and disaster relief efforts (Tomlin 2006, Lodree and Taskin 2007, Ratick et al. 2008, Falasca et al. 2008, Boin et al. 2010). This implies the strategic planning and positioning of supply chain parties. However, recent trends in the dynamics of market places and the resulting complex supply chain procedures increase the importance of handling uncertainties which emerge at the operational level. Effectively managing operational risks directly improves financial performance (Pettit et al. 2010; Sheffi 2005).

In recent studies, resilience, as 'the ability of a supply chain to cope with change', is regarded as the next phase in the evolution of traditional, place-centric enterprise structures to highly virtualized, customer-centric structures that enable people to work anytime, anywhere.
Resilient supply networks should align its strategy and operations to adapt to risk that affect its capacities. There are 4 levels of supply chain resilience. First is reactive supply chain management. Second is internal supply chain integration with planned buffers; then comes collaboration across extended supply chain networks. Finally is a dynamic supply chain adaptation and flexibility (Nagurney, 2006).
It is not about responding to a one-time crisis, or just having a flexible supply chain. It is about continuously anticipating and adjusting to discontinuities that can permanently impair the value preposition of a core business with special focus on delivering ultimate customer centricity. Strategic resilience, therefore, requires continuous innovation with respect to product structures, processes, but also corporate behaviour. Recent research suggests that supply chains can also contribute to firm resilience (Wieland and Wallenburg, 2013).

Modern supply chain management necessitates effective supplier selection to meet a variety of business goals in perspectives of different supply chain philosophies adapted. Supplier selection is the process by which firms identify, evaluate, and contract with suppliers. The supplier selection process deploys a tremendous amount of a firm's financial resources. In return, firms expect significant benefits from contracting with suppliers offering high value.
The green supplier selection process is one of the key operational tasks for sustainable supply chain partnership. The powerful supplier should enhance the performance of the supply chain

with environmental, social and economic aspects [Kannan et al., 2012]. Due to the current awareness in the environmental aspects, the assortment of the supplier has turned their way and made focus on the green criteria base more than a habitual way [Lee et al., 2009]. With increasing government regulation and stronger public awareness in environmental protection, firms today simply cannot ignore environmental issues if they want to survive in global market. In addition to complying with the environmental regulations for selling products in certain countries, firms need to implement strategies to voluntarily reduce the environmental impacts of their products. The integration of environmental, economic and social performances to achieve sustainable development is a major business challenge for the new century. Environmental management is becoming more and more important for corporations as the emphasis on the environmental protection by organizational stakeholders, including stockholders, governments, customers, employees, competitors and communities, keeps increasing. Programs such as design for the environment, life cycle analysis, total quality environmental management, green supply chain management and ISO 14000 standards are popular for environmentally conscious practices. A green supplier evaluation system is indeed necessary for a firm in determining the suitability of a supplier as a partner in the green supply chain [Nimawat and Namdev, 2012].

Apart from efficient supplier selection in green supply chain management context; firms should also focus on identifying potential suppliers to help in supply chain disruption scenario. Therefore, suppliers' resiliency strategies must be considered along with general strategies in the supplier selection process.

Because, supply chains are increasingly becoming vulnerable to catastrophic events/incidents, that may be natural or man-made. For example, hurricanes, tsunamis and floods are natural disasters, whereas manmade disasters may be strikes, terrorist attacks, etc. Disruption is a Low Probability High Intensity Event (LPHI) which may cause a long term system unbalance. Therefore, planning for disruption scenarios is becoming a key strategic consideration in the supplier evaluation as well as selection process to keep pace with serving a globally competitive market. Thus, proactive planning for these types of event should be a high priority for supply chain managers. A catastrophic event has a very low probability of occurrence but has adverse consequences if and when it is incurred (Haldar et al., 2014). That's why resiliency planning is becoming an important aspect in the supplier selection process to keep pace with serving a globally competitive business scenario.

1.2 State of Art

Li and O'Brien (1999) focused on improving SC efficiency and effectiveness under four criteria, profit, lead time performance, delivery promptness and waste elimination, instead of the cost alone. Gunasekaran et al. (2001) developed a framework for measuring strategic, tactical and operational level performance in a supply chain. The authors emphasized on performance measures dealing with suppliers, delivery performance, customer-service, and inventory and logistics costs in a SCM. In developing the metrics, an effort was also made to align and relate them to customer satisfaction. Lai et al. (2002) developed a measurement instrument for supply chain performance (SCP) in transport logistics. A 26-item SCP measurement instrument was constructed, reflecting service effectiveness for shippers, operations efficiency for transport logistics service providers, and service effectiveness for consignees. Persson and Olhager (2002) presented a supply chain simulation study for a real case, concerned with the manufacturing of mobile communication systems. The study evaluated alternative supply chain designs with respect to quality, lead times and costs as the key performance parameters. The study also focused on the understanding of the interrelationships among these and other parameters, relevant for the design of the supply chain structure.

Kleijnen and Smits (2003) made a critical analysis of various performance metrics for supply chain management (SCM), used by a specific manufacturing company. The paper proposed to deal with multiple metrics in SCM via the balanced scorecard. This paper distinguished four simulation types for SCM: (i) spreadsheet simulation, (ii) system dynamics, (iii) discrete-event simulation, and (iv) business games. These simulation types could explain the bullwhip effect, predict fill rate values, and educate and train users. Otto and Kotzab (2003) explored suitable metrics to measure the effectiveness of SCM. The different metrics referred to the main disciplines, which contributed to the field of SCM the most: System Dynamics, Operations Research/Information Technology, Logistics, Marketing, Organization and Strategy. Vickery et al. (2003) examined the performance implications of an integrated supply chain strategy, with customer service performance followed by financial performance as performance constructs. The results showed positive direct relationships between (1) integrated information technologies and supply chain integration, (2) supply chain integration and customer service, and (3) customer service and firm performance. The relationship of supply chain integration to financial performance was found indirect, through customer service; i.e., customer service was found to fully (as opposed to partially) mediate the relationship between supply chain integration and firm performance for first tier suppliers in the automotive industry. Gunasekaran et al. (2004)

developed a framework to promote a better understanding of the importance of SCM performance measurement and metrics through empirical studies of selected British companies. Perona and Miragliotta (2004) presented the results of an empirical research program devoted to investigate how complexity could affect a manufacturing company's performances, and those of its supply chain. The work focused on sales, inbound and outbound logistics, product and process engineering, production and organizational issues. The work suggested that the ability to control complexity within manufacturing and logistics systems could be regarded as a core competence in order to jointly improve efficiency and effectiveness at a supply chain wide scale. Li et al. (2006) conceptualized and developed five dimensions of SCM practice (strategic supplier partnership, customer relationship, level of information sharing, quality of information sharing, and postponement) and examined the relationships between SCM practices, competitive advantage, and organizational performance. Data for the study were collected from 196 organizations and the relationships proposed in the framework were tested using structural equation modeling. The results indicated that higher levels of SCM practice could lead to enhanced competitive advantage and improved organizational performance. Also, competitive advantage could have a direct, positive impact on organizational performance.

Guiffrida and Nagi (2006) addressed strategies for improving delivery performance in a serial supply chain. Models were developed that incorporated the variability found in the individual stages of the supply chain into a financial measure that served as a benchmark for justifying the capital investment required to improve delivery performance within the supply chain to meet a targeted goal. Chen et al. (2007) investigated the performance of Collaborative Planning, Forecasting and Replenishment (CPFR) in relation to overall supply chain performance. By using simulation, the authors investigated four CPFR alternatives that were used in the adoption of collaboration strategies in industries. Retailers had traditionally played the hub role in supply chains in order to reduce the bullwhip effect, but the simulation covered in this paper confirmed that shifting the retailer (buyer-driven) collaboration to a manufacturer (supplier-driven) approach seemed to be a more viable option. Gunasekaran and Kobu (2007) attempted to determine the key performance measures and metrics in supply chain and logistics operations by considering the importance of nonfinancial measures and intangibles. Gaiardelli et al. (2007) proposed an integrated framework for the after-sales network performance measurement, and provided an empirical application to two automotive case companies and their official service network. The cases showed that performance measurement systems of different supply chain actors should be aligned in order to achieve strategic consistency. Berrah and Clivillé (2007) dealt with the supply chain performance formalization. The authors proposed to build performance measurement systems (PMSs) by linking an overall performance expression to elementary ones.

Bhagwat and Sharma (2007) developed a balanced scorecard for supply chain management that measured and evaluated day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and growth supported by three case studies applied in small and medium sized enterprises (SMEs) in India. Kim (2007) suggested a set of best organization structures for efficient supply chain management. This paper derived organization types for supply chain management according to the formalization and centralization level of an independent department responsible for supply chain management activities, and hierarchical relationship in organizational position and operational responsibility between the SCM department and existing other functional departments. This paper also identified organizational characteristics, which had significant influences on SCM performance by investigating the difference in performance across the proposed organization types. Xu et al. (2009) studied the supply chain performance evaluation of a furniture manufacture industry in the southwest of China. The authors identified the main uncertainty factors affecting evaluation process, and then analyzed using rough data envelopment analysis (RDEA) models. Cai et al. (2009) proposed a framework to improve the iterative key performance indicators (KPIs) accomplishment in a supply chain context. The proposed framework quantitatively analyzed the interdependent relationships among a set of KPIs. It could identify crucial KPI accomplishment costs and proposed performance improvement strategies for decision-makers in a supply chain. Olugu and Wong (2009) established the gap in knowledge in supply chain performance measurement using fuzzy logic operation. Both traditional and fuzzy logic approaches to supply chain performance measurement were scrutinized. Further scrutiny was carried out to establish potential research areas in the application of fuzzy logic operations in supply chain performance measurement. The supply chain performance measurement using fuzzy logic operation was identified as a new direction in measuring the uncertainty and ambiguity surrounding supply chain performance measurement.

Whicker et al. (2009) investigated (through the use of an industrial case study) how analysis of both time and cost could be combined to provide a more accurate view of supply chain performance which could lead to better informed decision making. The subsequent analysis provided an insight into the relationship between time and cost in supply chain processes and demonstrated how product could cost accumulate in the supply chain. Allesina et al. (2010) developed a quantitative measurement of complexity for a supply network based on network analysis focusing in particular on the concept of entropy of information. Eight indexes based on entropy were presented. These measures provided a meaningful analysis of the level of complexity in the whole supply network mapping the exchanges of goods between the different actors in the network. The proposed method took a holistic point of view to tackle the problem of supply network optimization. Trkman et al. (2010) investigated the relationship between analytical capabilities in the plan, source, make and deliver area of the supply chain and its performance using information system support and business process orientation as moderators. Structural equation modeling employed a sample of 310 companies from different industries from the USA, Europe, Canada, Brazil and China. The findings suggested the existence of a statistically significant relationship between analytical capabilities and performance. The moderation effect of information systems support was considerably stronger than the effect of business process orientation. The results provided a better understanding of the areas where the impact of business analytics might be the strongest.

Flynn et al. (2010) extended the developing body of literature on supply chain integration (SCI), which is the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organizational processes, in order to achieve effective and efficient flows of products and services, information, money and decisions, to provide maximum value to the customer. The authors studied the relationship between three dimensions of SCI, operational and business performance, from both a contingency and a configuration perspective. In applying the contingency approach, hierarchical regression was used to determine the impact of individual SCI dimensions (customer, supplier and internal integration) and their interactions on performance. In the configuration approach, cluster analysis was used to develop patterns of SCI, which were analyzed in terms of SCI strength and balance. Analysis of variance was used to examine the relationship between SCI pattern and performance. The findings of both the contingency and configuration approach indicated that SCI was related to both operational and business performance.

Chen and Yan (2011) constructed an alternative network DEA model that embodied the internal structure for supply chain performance evaluation. The authors took the perspective of organization mechanism to deal with the complex interactions in supply chain. Three different network DEA models were introduced under the concept of centralized, decentralized and mixed organization mechanisms, respectively. Efficiency analysis including the relationship between supply chain and divisions, and the relationship among the three different organization mechanisms were discussed. As a further extension, the authors investigated internal resource waste in supply chain. Koçóğlu et al. (2011) focused on the influence of supply chain integration (SCI) on information sharing and supply chain performance (SCP) and the role of information sharing in shaping SCP. The conceptual model comprised of 3 research hypotheses with 3 main constructs; SCI, information sharing and SCP. The authors categorized the constructs as; integration with customers, integration with suppliers, and the inter-organizational integration as the levels of SCI; the four types of information sharing namely; information sharing with customers, information sharing with suppliers, inter-functional information sharing, and intra-organizational information sharing; and the 4 constructs of SCP which were expenses of costs, asset utilization, supply chain reliability, and supply chain flexibility and responsiveness. The hypotheses were tested via an empirical study in which data are collected from 158 manufacturing firms in Turkey mainly Marmara Region, that were among the top 500 Turkish manufacturing firms of 2010 listed by Istanbul Chamber of Commerce. The results suggested that the role played by SCI was found critical in information sharing process as it reinforced connectedness, coordination and collaboration among SC members.

Stefanović and Stefanović (2011) introduced the architecture of a pervasive supply chain Performance Measurement (PM) system. The main system elements such as process model, metrics and data warehouse were described. Finally, a specialized PM web portal which enabled proactive performance monitoring and fosters the improvement and optimization was presented. Khilwani et al. (2011) proposed an effective modeling technique, the hybrid Petri-net, to efficiently handle the dynamic behavior of the supply chain. This modeling methodology embedded two enticing features, i.e. cost and batch sizes, in deterministic and stochastic Petri-net for the modeling and performance evaluation of supply chain networks. The model was subsequently used for risk management to investigate the issues of supply chain vulnerability and risk. In the test bed, a simple productive supply chain and an industrial supply chain were modeled with fundamental inventory replenishment policy. Subsequently, its performance was evaluated along with the identification and assessment of risk factors using analytical and simulation techniques respectively. Thus, this paper presented a complete package for industrial practitioners to model, evaluate performance and manage risky events in a supply chain.

Ruifeng and Subramaniam (2011) formulated an approximate model for the tandem manufacturing systems, where the inventory in each buffer was monitored based on the (s, Q) discipline. This model divided a multistage system into a series of primitive line segments, each of which was characterized by a continuous time discrete state Markov process. The model might be applied in two types of systems: (1) tandem flow lines with batch processing and (2) multi-factory manufacturing supply chain, with the requirement of inter-factory material transportation. Based on the model, a number of commonly used performance measures, including throughput, inventory, transportation frequency, etc., could be estimated. These estimates might enable manufacturers to evaluate the performance of the systems, and hence improve the management of production and inventory. Ganga and Carpinetti (2011) proposed a supply chain performance model based on fuzzy logic to predict performance based on causal relationships between metrics of the Supply Council Operations Reference model (SCOR) model. El-Baz (2011) presented a fuzzy decision making approach to deal with the performance measurement in supply chain systems. Thus, this paper presented a performance measurement approach based on fuzzy set theory and the pair-wise comparison of Analytical Hierarchy Process (AHP), which ensured the consistency of the designer's assignments of importance of one factor over another to find the weight of each of the manufacturing activity in the departmental organization.

Wu et al. (2012) developed a discrete time model, which could describe the characteristics of network-wide system disruptions and provide rapid performance evaluation of global supply chain networks (SCNs) with assembly structure. Considering system disruptions at any stage of the whole system, the authors developed new iterative methods to obtain the key performance measures of SCNs with assembly structure in both lost sales and backorder scenarios. Results suggested that component suppliers with higher reliability in the downstream stages would deliver better system performance in both lost sales and backorder scenarios. Cho et al. (2012) developed a framework of service supply chain performance measurement based on the strategic, tactical and operational level performance in a service supply chain. The emphasis was on performance measures dealing with service supply chain processes such as demand management, customer relationship management, supplier relationship management, capacity and resource management, service performance, information and technology management and service supply chain finance. In order to prioritize service supply chain performance measurement indicators to improve service supply chain performance, a methodology based on the extent fuzzy analytic hierarchy process was attempted. Govindan et al. (2012) attempted towards evaluation of performance measures and supply chain profit behavior under buyback, revenue sharing, quantity flexibility and advanced purchase discount contracts versus no coordination and wholesale price systems.

Elgazzar et al. (2012) developed a performance measurement method which linked supply chain (SC) processes' performance to a company's financial strategy through demonstrating and utilizing the relationship between SC processes' performance and a company's financial performance. The Dempster Shafer/Analytical Hierarchy Processes (DS/AHP) model was employed to link SC processes' performance to the company's financial performance through determining the relative importance weights of SC performance measures with respect to the priorities of financial performance. The paper also introduced a Supply Chain Financial Link Index (SCFLI) to test the extent to which SC processes' performance has been linked to the company's financial strategic objectives. This index offered an effective supply chain management (SCM) tool to provide continuous feedback on SC performance and identify the appropriate corrective actions.

Najmi and Makui (2012) proposed a conceptual model for measuring supply chain (SC) performance which could be used for most organizations with the same class at various industries. The methodology was based on a combination of the analytical hierarchy process (AHP) and Decision Making Trial and Evaluation Laboratory (DEMATEL) methods. The DEMATEL and AHP were used for understanding the relationship between comparison metrics and integration to provide a value for performance, respectively. Tavana et al. (2013) presented a case study to exhibit the efficacy of the network epsilon-based DEA model to solve a supply chain performance evaluation problem in the semiconductor industry. Fan et al. (2013) proposed a model using 5 Dimensional Balanced Scorecard (5DBSC) and LMBP (Levenberg–Marquardt Back Propagation) neural network for performance evaluation of supply chains. This model could be used to evaluate, predict and optimize the performance of a SC. Chen and Gong (2013) presented a method for evaluating the performance of a supply chain network. The main index was cost factors, which included four categories: production costs, disruption costs, co-ordination costs, and vulnerability costs.

Jakhar and Barua (2014) proposed a comprehensive evaluation tool and decision model to help the practitioners to gauge their supply chain performance and guide them in decision-making for further improvements. The five important performance evaluation criteria (supply chain planning performance, supply chain partnership performance, production performance, delivery and logistic performance and customer service and satisfaction performance) and corresponding 19 sub-criteria were identified. An integrated methodology of structural equation modeling (SEM) and fuzzy analytic hierarchy process (FAHP) were applied to the proposed model to a real case study of Indian textile–apparel–retail supply chain network. Medini and Rabénasolo (2014) analyzed the performance of supply chains by using agent-based simulation. The proposed agents were based on the Supply Chain Operations Reference (SCOR) model. The paper discussed different effects of supply chain configurations and the competitive environment on SCOR performance indicators from a global point of view. A modified version of a traditional SCOR indicator was introduced with the a priori knowledge of the network connectivity.

Sarkis (2003) presented a strategic decision framework to aid managerial decision making in the area of environmentally conscious business practices. The focus of this paper was on the components and elements of green supply chain management and how they served as a foundation for the decision framework. The authors explored the applicability of a dynamic non-linear multi-attribute decision model, defined as the analytical network process, for decision making within the green supply chain. Zhu and Sarkis (2004) examined the relationships between green supply chain management (GSCM) practice and environmental and economic performance. Using moderated hierarchical regression analysis, the authors evaluated the general relationships between specific GSCM practices and performance. The authors then investigated how two primary types of management operations philosophies, quality management and just-in-time (or lean) manufacturing principles, influenced the relationship between GSCM practices and performance. Hervani et al. (2005) provided an overview of the various issues related to environmental (green) supply chain management performance measurement. The studies seek to integrate works in supply chain management, environmental management, and performance management into one framework. The work provided an integrative framework for study, design and evaluation of green supply chain management performance tools.

Rao and Holt (2005) endeavored to identify potential linkages between green supply chain management, as an initiative for environmental enhancement, economic performance and competitiveness amongst a sample of companies in South East Asia. A conceptual model was developed from literature sources and data collected using a structured questionnaire mailed to a sample of leading edge ISO14001 certified companies in South East Asia followed by structural equation modeling. This paper presented the first empirical evaluation of the link between green supply chain management practices, increased competitiveness and improved economic performance amongst a sample of organizations in South East Asia. Kainuma and Tawara (2006) extended the range of the supply chain to include re-use and recycling throughout the life cycle of products and services. The authors proposed the multiple attribute utility theory method for assessing a supply chain. The authors considered this approach to be one of the ''the lean and green supply chain'' methods. It was possible to evaluate the performance of a supply chain not only from a managerial viewpoint but also from an environmental performance viewpoint.

Zhu et al. (2007) explored the GSCM pressures/drivers (motivators), initiatives and performance of the automotive supply chain using an empirical analysis of 89 automotive enterprises within China. The results showed that the Chinese automobile supply chain enterprises had experienced high and increasing regulatory and market pressures and at the same time had strong internal drivers for GSCM practice adoption. However, their GSCM implementation, especially with consideration of external relationships, was found poor. In furthering this analysis the authors investigated one specific organization in this supply chain, the Dalian Diesel Engine Plant, and how this pioneering company had addressed the issues identified by the broader empirical analysis.

Using a survey of North American manufacturers, (Vachon and Klassen, 2008) examined the impact of environmental collaborative activities on manufacturing performance. Environmental collaboration was defined specifically to focus on inter-organizational interactions between supply chain members, including such aspects as joint environmental goal setting, shared environmental planning, and working together to reduce pollution or other environmental impacts. These practices could be directed either upstream toward suppliers or downstream toward customers. The influence of collaboration in each direction was empirically assessed for multiple objective and perceptual measures of manufacturing performance using a sample of plants in the package printing industry. Generally, the benefits of collaborative green practices with suppliers were broadest. In contrast, collaboration with customers yielded mixed outcomes. Overall, evidence emerged that upstream practices were more closely linked with process-based performance, while downstream collaboration was associated with product-based performance.

Large and Thomsen (2011) identified five potential drivers of green supply management performance: green supply management capabilities, the strategic level of the purchasing department, the level of environmental commitment, the degree of green supplier assessment, and the degree of green collaboration with suppliers. These constructs were used to form a structural model explaining the environmental performance and the purchasing performance. The model was analyzed with SmartPLS 2.0 using data collected among German purchasers. The results suggested that the degree of green supplier assessment and the level of green collaboration exerted direct influence on environmental performance. These two practices were driven by the strategic level of the purchasing department and the level of environmental commitment of the firm. Whereas commitment influenced green assessment directly, the impact of commitment on green collaboration was mediated by the capabilities of the purchasing department. Furthermore, the results showed that environmental performance had a positive impact on purchasing performance.

Olugu et al. (2011) developed a set of measures for evaluating the performance of the automobile green supply chain. This study reviewed various literatures on green supply chain performance measurement, environmental management, traditional supply chain performance measurement, and automobile supply chain management. In order to comprehensively and effectively establish the relevant measures, a suitable framework which considered the automobile green supply chain as a two-in-one chain was adopted. This two-in-one chain comprised a forward and backward chain for the automobile industry. Consequently, 10 measures with 49 metrics and 6 measures with 23 metrics were identified and developed for the forward and backward chains, respectively. This study contributed to the advancement of knowledge by pioneering the development of a set of holistic measures for evaluating the performance of the automobile green supply chain. Zhu et al. (2011) investigated whether different Chinese manufacturer clusters varying in their extent of implementing GSCM existed from this ecological modernization perspective. The results highlighted the varying pace of Chinese manufacturers to ecologically modernize with GSCM practices and the significance of regulatory pressure to diffuse the practices adoption by Chinese manufacturing industry.

Azevedo et al. (2011) investigated the relationships between green practices of supply chain management and supply chain performance. This relationship was investigated in the context of the automotive industry. Five research propositions were suggested and tested with empirical data derived from five case studies taken from the Portuguese automotive supply chain. The data analysis identified the most important green practices considered by managers, as well as the performance measures that were most appropriate and most widely used as means to evaluate the influence of green practices on supply chain performance. A conceptual model was derived from the data analysis and it could be used to assess the influence of green practices on supply chain performance. This model provided evidence as to which green practices had positive effects on quality, customer satisfaction and efficiency. It also identified the practices which had negative effects on supply chain performance. Lin et al. (2011) explored the green criteria that might influence the performance of the automobile manufacturing industry, using the fuzzy set theory and Decision Making Trial and Evaluation Laboratory. The hybrid method evaluated its performance to find key criteria in improving the manufacturers' green performance. Findings showed that the increase of cost for purchasing environmentally friendly material was the most influential and significant criterion, while the pollution control initiatives was the most effective criterion.

Uysal (2012) proposed an integrated model for sustainable performance measurement in supply chain. The Decision Making Trial and Evaluation Laboratory (DEMATEL) Method was applied to deal with the importance and causal relationships between the sustainable performances measurements criteria by considering the interrelationships among them. In order to analyze the abovementioned graph structure, a multi-criteria decision making methods of graph theory and matrix approach were used. Lee et al. (2012) explored green supply chain management (GSCM) practices and their relationship with organizational performance. This research focused on the effect of GSCM efforts and other organizational factors on firm performance of small and medium enterprises (SMEs) that served as suppliers to large customer firms in the electronics industry. This study developed a research model relating GSCM practice and business performance through three organizational variables (employee satisfaction, operational efficiency, and relational efficiency) as moderators. Iirajpour et al. (2012) presented a framework for assessment of the green suppliers with accountability components of the organizations regarding society which considered cost issues for the selection of suppliers and their responsibilities toward society and the surrounding world. TOPSIS method was used for the selection of the greenest supplier. Lin (2013) examined the influential factors among eight criteria of three main GSCM practices, namely practices, performances, and external pressures. To deal with the vagueness of human being's perceptions, this study utilized the fuzzy set theory and decision making trial and evaluation laboratory method to form a structural model to find out the cause and effect relationships among criteria.

Zhu et al. (2013) developed and empirically tested a theoretical model on different types of institutional pressures motivating manufacturing enterprises to pursue green supply chain management (GSCM) practices and commensurate performance outcomes. Using a sample of 396 Chinese manufacturers, path analysis was used to evaluate the many structural links. The statistic results showed that institutional pressures drove the manufacturer adoption of internal GSCM practices which in turn related to their external GSCM practices adoption. The statistic results also suggested that GSCM practices do not directly affect economic performance, but could improve it indirectly. Falatoonitoosi et al. (2013) developed a causal evaluation model to guide selection of qualified suppliers by prioritizing various criteria and mapping causal relationships to find effective criteria to improve green supply chain. The case studies aimed to model and examine the influential and important main GSCM practices, namely, green logistics, organizational performance, green organizational activities, environmental protection, and green supplier evaluation. In the case study, decision-making trial and evaluation laboratory technique was applied to test the developed model. The result of the case study showed only "green supplier evaluation" and "green organizational activities" criteria of the model were in the cause group and the other criteria were in the effect group.

Dey and Cheffi (2013) developed and deployed an analytical framework for measuring the environmental performance of manufacturing supply chains. This work's theoretical bases combined and reconciled three major areas: supply chain management, environmental management and performance measurement. This research developed an innovative GSC performance measurement framework by integrating supply chain processes (supplier relationship management, internal supply chain management and customer relationship management) with organizational decision levels (both strategic and operational). The proposed framework was applied to three selected manufacturing organizations in the UK. Their GSC performance was measured and benchmarked by using the analytic hierarchy process (AHP).

Bhattacharya et al. (2013) delineated a green supply chain (GSC) performance measurement framework using an intra-organizational collaborative decision-making (CDM) approach. A fuzzy analytic network process (ANP)-based green-balanced scorecard (GrBSc) was used within the CDM approach to assist in arriving at a consistent, accurate and timely data flow across all cross-functional areas of a business. A green causal relationship was established and linked to the fuzzy ANP approach. The causal relationship involved organizational commitment, eco-design, GSC process, social performance and sustainable performance constructs. Sub-constructs and sub-sub-constructs were also identified and linked to the causal relationship to form a network. Savino et al. (2013) conducted an exploratory case-based research on the SC of fresh chestnuts in order to integrate environmental concepts in the value chain approach, with a concurrent evaluation of sustainability improvements and their economic impact. Within the value chain configuration, environmental KPIs were defined for the specific case study and a logistic environmental model was developed. Within the model, an evaluation of carbon footprint for this SC was proposed, along with its possible improvements. Diabat et al. (2013) explored the practices and performances of the GSCM; considered the relationship between green supply chain practices (initiatives) and performance outcomes. In this paper, two questionnaires were developed and a survey conducted to assess the importance of GSCM practices and performances in an automotive company in a developing country using a fuzzy multiple criteria decision-making method. The result of this paper presented practical guidance for managers in performing GSCM practices by ranking GSCM practices according to their importance which leads to improving GSCM performances. Mirhedayatian et al. (2014) proposed a novel network DEA model for evaluating the GSCM in the presence of dual-role factors, undesirable outputs, and fuzzy data.

Pujawan (2004) presented a framework for assessing flexibility of a supply chain. Four main parts of flexibility were identified including flexibility of the product delivery system, production system, product development, and supply system. In each of these parts, a number of pertinent elements were defined. A general guideline for conducting flexibility assessment was also presented. Sánchez and Pérez (2005) explored the relationship between the dimensions of supply chain flexibility and firm performance in a sample of automotive suppliers. Gong (2008) developed a supply chain flexibility model comprising labor flexibility, machine flexibility, routing flexibility, and information technology, with total system flexibility measured by an economic index. Outputs from the model could assist in making suitable production decisions to produce multiple products under an uncertain environment. Tachizawa and Giménez (2009) focused on supply flexibility, i.e., the ability of the purchasing function to respond in a timely and cost effective manner to changing requirements of purchased components, in terms of volume, mix and delivery date. The authors performed a regression analysis of the effectiveness of the different supply flexibility sources. The authors conducted a stepwise regression, setting the supply flexibility sources as independent variables and the three dimensions of supply flexibility (identified in the factor analysis) as dependent variables. In order to refine the models and increase the generalizability of the study, some control variables (i.e., firm revenue and flexibility focus) were also included in the regression analysis. Results suggested that each dimension of supply flexibility was associated with a particular group of sources, i.e., the sources used to increase a certain dimension of supply flexibility (e.g., supplier responsiveness) may be ineffective for another dimension (e.g., adaptability).

Winkler (2009) identified resources, objects and parameters of supply chain flexibility and highlighted the potentials of a strategic supply chain network to realize high supply chain flexibility. It was demonstrated how to manage the structural, technological and human potentials of the strategic supply chain network to gain outstanding supply chain flexibility. Chuu (2011) proposed a group decision-making structure model of flexibility in supply chain management development. This study presented a framework for evaluating supply chain flexibility comprising two parts, an evaluation hierarchy with flexibility dimensions and related metrics, and an evaluation scheme that used a three-stage process to evaluate supply chain flexibility. This study proposed an algorithm for determining the degree of supply chain flexibility using a fuzzy linguistic approach. Evaluations of the degree of supply chain flexibility could identify the need to improve supply chain flexibility, and identify specific dimensions of supply chain flexibility as the best directions for improvement. Merschmann and Thonemann (2011) addressed the relationship between environmental uncertainty, supply chain flexibility, and firm performance through a survey of German manufacturing companies. Baç and Erkan (2011) proposed a model to evaluate supply chain performance and flexibility. The authors developed a mathematical model to evaluate supply chain performance using some key performance indicators. This model could be used to evaluate the flexibility characteristics of logistic, market, supplier, machine, labor, information system, and routing of the supply chain.

Moon et al. (2012) adopted a comprehensive and rigorous procedure to develop a multifaceted scale for supply chain flexibility (SCF) through an empirical investigation. The results of a confirmatory factor analysis suggested that SCF could be operationalized as a second-order factor model comprising four dimensions, namely: sourcing flexibility, operating system flexibility, distribution flexibility, and information system flexibility. A series of goodness-of-fit indices further demonstrated that this scale was internally consistent, reliable, and valid. The various findings suggested in the study provided a more succinct picture of SCF, and the well-validated scale could be used as a basis for further research and theoretical groundwork in the field of supply chain management. Chandrakar et al. (2012) intended to measure the degree of flexibility required for a two stage supply chain and assessing both the supplier flexibility and the assembler flexibility. In this paper, nine configurations of the SC were considered resulting from the combination of the three degrees of supplier and manufacturer flexibility, i.e. no flexibility, limited flexibility and total flexibility, respectively. Simulation model representing the different flexibility configurations were evaluated and the performance of each configuration analyzed to determine the flexibility configuration suitable to a supply chain. In particular the performance analysis of lead time, work-in-process, service level and cost were measured to determine the suitable flexibility. Sokri (2014) provided a comprehensive definition of military supply chain (SC) flexibility, as well as performance measures to evaluate it. Volume flexibility was measured as the coefficient of variation of the demand quantity. Delivery side was measured in two stages using two ratios: customer satisfaction ratio and delivery flexibility ratio. Novel performance measures were developed to assess the volume flexibility (the ability to change the level of moved products) and delivery flexibility (the ability to meet short lead times).

Kainuma (2012) focused on the supply chain performance and resilience of Japanese firms. The author considered the case of Great East Japan Earthquake which caused deterioration of SCM performance and the Japanese firms were forced to adopt the supply chain resiliency. Azvedo et al. (2011) suggested an Index entitled GResilient Index to assess the greenness and resilience of the automotive companies and corresponding supply chain. An integrated assessment model was proposed based on Green and Resilient practices. These practices were weighted according to their importance to the automotive supply chain competitiveness. The Delphi technique was used to obtain the weights for the focused supply chain paradigms and corresponding practices. The Index could be effectively employed for functional benchmarking among competing companies and supply chains. Ferreira et al. (2012) proposed a fuzzy LARG (Lean, Agile, Resilient, Green) index model for supply chain (SC) performance assessment. Through its performance evaluation, SCs were able to measure their level of efficiency and its ability to react, efficiently, to changes in a competitive environment. The case study presented showed that due to the uncertainties surrounding the SC's environment and to the qualitative description of the SC's practices, fuzzy logic could provide an effective assessment tool able to quickly incorporate changes in the SC's business policy.

Azevedo et al. (2012) proposed a conceptual model about the influence of lean, agile, resilient, and green (LARG) practices on supply chain operational, economic and environmental performance. Among the suggested LARG practices, the ones influencing more the supply chain performance were the just-in-time and also the supplier relationships. Also the supply chain performance measures with more LARG practices influencing them were the inventory levels and the time, that was, the supply chain's operational performance was the most affected by the simultaneous paradigms deployment in the supply chain. Falasca et al. (2008) developed a quantitative approach for assessing supply chain resilience to disasters. The authors proposed a simulation-based framework that incorporated concepts of resilience into the process of supply chain design. In this context, resilience was defined as the ability of a supply chain system to reduce the probabilities of disruptions, to reduce the consequences of those disruptions, and to reduce the time to recover normal performance. The proposed decision framework incorporated three determinants of supply chain resilience (density, complexity, and node criticality) and discussed their relationship to the occurrence of disruptions, to the impacts of those disruptions on the performance of a supply chain system and to the time needed for recovery. Different preliminary strategies for evaluating supply chain resilience to disasters were also identified in this research.

Spiegler et al. (2012) established clearly elucidated performance criteria that encapsulated the attributes of resilience. Apart from the concept of resilience (as readiness, responsiveness and recovery), the authors identified robustness as a necessary condition that would complement resilience. It was found that the Integral of the Time Absolute Error (ITAE) was an appropriate control engineering measure of resilience whilst applied to inventory levels and shipment rates. The authors used the ITAE to evaluate an often used benchmark model of make-to-stock supply chains consisting of three decision parameters. Findings suggested that supply chains would experience drastic changes in their resilience performance when lead-time would tend to change.

Tam and Tummala (2001) formulated an AHP-based model and applied to a real case study in selecting a vendor for a telecommunications system. Kumar et al. (2004) applied a fuzzy goal programming approach for solving the vendor selection problem with multiple objectives, in which some of the parameters were fuzzy in nature. A vendor selection problem was formulated as a fuzzy mixed integer goal programming vendor selection problem that included three primary goals: minimizing the net cost, minimizing the net rejections, and minimizing the net late deliveries subject to realistic constraints regarding buyer's demand, vendors' capacity, vendors' quota flexibility, purchase value of items, budget allocation to individual vendor, etc. Hong et al. (2005) proposed an effective supplier selection method to maintain a continuous supply-relationship with suppliers. The authors suggested a mathematical programming model that considered the change in suppliers' supply capabilities and customer needs over a period in time. The authors designed a model which not only maximized revenue but also satisfied customer needs. The suggested model was applied to supplier selection and management of the agriculture industry in Korea. Shyur and Shih (2006) formulated the vendor evaluation problem by the combined use of the multi-criteria decision-making (MCDM) approach and a proposed five-step hybrid process, which incorporated the technique of an analytic network process (ANP). Then the modified TOPSIS (technique for order performance by similarity to idea solution) was adopted to rank competing products in terms of their overall performances.
Kumar et al. (2006) treated a vendor selection problem (VSP) as a ''fuzzy Multi-objective Integer Programming Vendor Selection Problem'' (f-MIP_VSP) formulation that incorporated the three important goals: cost-minimization, quality-maximization and maximization of on-time-delivery-with the realistic constraints such as meeting the buyers' demand, vendors' capacity, vendors' quota flexibility, etc.
Amid et al. (2006) developed a fuzzy multi-objective linear model to overcome the vagueness of the information in relation to suppliers' selection. An asymmetric fuzzy-decision making technique was applied to enable the decision-maker to assign different weights to various criteria. Gencer and Gürpinar (2007) developed a model aiming the usage of analytic network process (ANP) in supplier selection to the evaluation of the relations between supplier selection criteria in a feedback systematic. The proposed model was implemented in a company of electronic. Huang and Keskar (2007) presented an integration mechanism in terms of a set of

comprehensive and configurable metrics arranged hierarchically that took into account product type, supplier type, and OEM/supplier integration level. An optimal supplier selection decision was made based on this chosen set of metrics, achieving a strategic fit between the firm's business model and its supply chain strategy. Sanayei et al. (2008) proposed an integrated approach of multi-attribute utility theory (MAUT) and linear programming (LP) for rating and choosing the best suppliers and defining the optimum order quantities among selected ones in order to maximize total additive utility. Özgen et al. (2008) developed an integration of the analytic hierarchy process (AHP) and a multi-objective possibilistic linear programming (MOPLP) technique to account for all tangible, intangible, quantitative, and qualitative factors to evaluate and select suppliers and to define the optimum order quantities assigned to each. A multi-objective linear programming technique was first employed to solve the problem. To model the uncertainties encountered in the integrated supplier evaluation and order allocation methodology, fuzzy theory was adopted. Hence, possibilistic linear programming (PLP) was proposed for solving the problem.

Demirtas and Ustun (2008) proposed an integrated approach of analytic network process (ANP) and multi-objective mixed integer linear programming (MOMILP) to consider both tangible and intangible factors in choosing the best suppliers and define the optimum quantities among selected suppliers to maximize the total value of purchasing and minimize the budget and defect rate. The priorities were calculated for each supplier by using ANP. Four different plastic molding firms working with a refrigerator plant were evaluated according to 14 criteria that were involved in the four clusters: benefits, opportunities, costs and risks (BOCR). Ng (2008) proposed a weighted linear program for the multi-criteria supplier selection problem. In addition to mathematical formulation, this paper studied a transformation technique which enabled the said model to be solved without an optimizer. The model for multi-criteria supplier selection problem could be easily implemented with a spreadsheet package. Ha and Krishnan (2008) outlined a hybrid method, incorporating multiple techniques into an evaluation process, in order to select competitive suppliers in a supply chain. It enabled a purchaser to do single sourcing and multiple sourcing by calculating a combined supplier score (CSS), which accounted for both qualitative and quantitative factors that impact on supply chain performance. By performing a cluster analysis, it drew a supplier map (SM) so as to position suppliers within the qualitative and quantitative dimensions of performance efficiency, and to select a portfolio of suppliers from supplier segments, which were different in performance with regard to key factors.

Chou and Chang (2008) presented a strategy-aligned fuzzy simple multi-attribute rating technique (SMART) approach for solving the supplier/vendor selection problem from the perspective of strategic management of the supply chain (SC). The majority of supplier rating systems obtained their optimal solutions without considering firm operations management (OM)/SC strategy. The proposed system utilized OM/SC strategy to identify supplier selection criteria. A fuzzy SMART was applied to evaluate the alternative suppliers, and dealt with the ratings of both qualitative and quantitative criteria. The final decision-maker incorporated the supply risks of individual suppliers into final decision making. Faez et al. (2009) focused on a case-based reasoning (CBR) approach for solving the VSP. The vague nature of some selection criteria was incorporated by utilizing the linear membership function of fuzzy type to quantify the vagueness in decision parameters. Moreover, a mixed integer programming model was employed to simultaneously consider suitable vendor selection and order allocation; due to the purchase situation of vendors derived from the CBR system, and with respect to such realistic constraints as meeting the buyer's demand, vendors' capacity, etc. Lee (2009) proposed an analytical approach to select suppliers under a fuzzy environment. A fuzzy analytic hierarchy process (FAHP) model, which incorporated the benefits, opportunities, costs and risks (BOCR) concept, was constructed to evaluate various aspects of suppliers. Guneri et al. (2009) presented an integrated fuzzy and linear programming approach to the supplier selection problem. Firstly, linguistic values expressed in trapezoidal fuzzy numbers were applied to assess weights and ratings of supplier selection criteria. Then a hierarchy multiple model based on fuzzy set theory was expressed and fuzzy positive and negative ideal solutions were used to find each supplier's closeness coefficient. Finally, a linear programming model based on the coefficients of suppliers, buyer's budgeting, suppliers' quality and capacity constraints was developed and order quantities assigned to each supplier according to the linear programming model.

Boran et al. (2009) proposed TOPSIS method combined with intuitionistic fuzzy set to select appropriate supplier in group decision making environment. Intuitionistic fuzzy weighted averaging (IFWA) operator was utilized to aggregate individual opinions of decision makers for rating the importance of criteria and alternatives. Liao and Kao (2010) integrated the Taguchi loss function, analytical hierarchy process (AHP) and multi-choice goal programming (MCGP) model for solving the supplier selection problem. Sanayei et al. (2010) proposed a hierarchy MCDM model based on fuzzy sets theory and VIKOR method to deal with the supplier selection problems in the supply chain system. Bhattacharya et al. (2010) identified a concurrent engineering approach integrating analytic hierarchy process (AHP) with quality function deployment (QFD) in combination with cost factor measure (CFM) delineated to rank and subsequently select candidate-suppliers under multiple, conflicting-in-nature criteria environment within a value-chain framework. Li and Zabinsky (2011) developed a two-stage stochastic programming (SP) model and a chance-constrained programming (CCP) model to determine a minimal set of suppliers and optimal order quantities with consideration of business volume discounts.

Amid et al. (2011) proposed a weighted max–min model for fuzzy multi-objective supplier selection in a supply chain. Amin et al. (2011) applied a quantified SWOT (Strengths, Weaknesses, Opportunities and Threats) in the context of supplier selection. In addition, the fuzzy logic and triangular fuzzy numbers were integrated with SWOT analysis to deal with vagueness of human thought. SWOT analysis could consider both qualitative and quantitative criteria. The managers could understand the position of suppliers in a competitive environment with a glance at SWOT matrix. Moreover, a fuzzy linear programming model was proposed to determine how much should be purchased from each supplier. Zeydan et al. (2011) reported a 2-stage combined methodology for supplier selection and performance evaluation. In the first stage, qualitative performance evaluation was performed by using fuzzy AHP (Analytic Hierarchy Process) in finding criteria weights and then fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was utilized in finding the ranking of suppliers. So, qualitative variables could be transformed into a quantitative variable for using in DEA (Data Envelopment Analysis) methodology as an output called quality management system audit. In the second stage, DEA was performed with one dummy input and four output variables, namely, quality management system audit, warranty cost ratio, defect ratio, quality management.

Kilincci and Onal (2011) investigated a supplier selection problem of a well-known washing machine company in Turkey; a fuzzy analytic hierarchy process based methodology was used to select the best supplier firm providing the most customer satisfaction for the criteria determined. Lin (2012) proposed to adopt the fuzzy analytic network process (FANP) approach first to identify top suppliers by considering the effects of interdependence among selection criteria and to handle inconsistent and uncertain judgments. FANP was then integrated with fuzzy multi-objective linear programming (FMOLP) in selecting the best suppliers for achieving optimal order allocation under fuzzy conditions. Erdem and Göçen (2012) developed a decision support system (DSS) for the improvement of supplier evaluation and order allocation decisions in a supply chain. Initially, an analytic hierarchy process (AHP) model was developed for qualitative and quantitative evaluation of suppliers. Based on these evaluations, a goal programming (GP) model was developed for order allocation among suppliers. The models were integrated into a DSS that provides a dynamic, flexible and fast decision making environment. The DSS environment is tested at the purchasing department of a manufacturer and feedbacks are obtained.

Handfield et al. (2002) illustrated the use of Analytic Hierarchy Process (AHP) as a decision support model to help managers understand the trade-offs between environmental dimensions. The authors demonstrated how AHP could be used to evaluate the relative importance of various environmental traits and to assess the relative performance of several suppliers along these traits. The authors also examined how AHP could be incorporated into a comprehensive information system supporting Environmentally Conscious Purchasing (ECP). Humphreys et al. (2003) presented a framework for integrating environmental factors into the supplier selection process. Boosothonsatit et al. (2012) proposed a decision support system to take into account environmental as well as traditional objectives. The proposed model aimed at selecting environmentally sustainable suppliers based on generic simulation model in order to minimize cost, lead time, and environmental impact as multi-objectives.

Agarwal and Vijayvargy (2012) presented a methodology to evaluate suppliers using portfolio analysis based on the analytical network process (ANP) and environmental factors. This paper introduced green criteria into the framework of supplier selection criteria. The paper discerned various characteristics of the suppliers and also produced recommendations on supplier management for an exemplary case scenario. It also provided insight into the role of intangible factors in decisions related to supply chain. The methodology generated decision rules relating various attributes to the performance outcomes. Lu et al. (2007) presented an innovative method to evaluate the effectiveness of projects supplying GSC concept. Specifically, a multi-objective decision making process for GSC management (GSCM) was presented to help the supply chain manager in measuring and evaluating suppliers' performance based on an analytical hierarchy process (AHP) decision-making method. In addition, to reduce subjective bias in designing a weighting system, a fuzzy logic process was used to modify the AHP. Lee et al. (2009) proposed a model for evaluating green suppliers. The Delphi method was applied first to differentiate the criteria for evaluating traditional suppliers and green suppliers. A hierarchy was constructed next to help evaluate the importance of the selected criteria and the performance of green suppliers. To consider the vagueness of experts' opinions, the fuzzy extended analytic hierarchy process was exploited. Dehghani et al. (2013) proposed an approach for supplier selection and allocations taking into account the environmental implications. In that case, the most important purchase items were identified using ABC analysis. Then, in order to evaluate the performance of suppliers accurately, performance evaluation criteria were identified and screened. Next, using Analytic Network Process (ANP), suppliers were ranked. Finally, orders allocation was done to qualified suppliers through implementing a linear multi-objective programming model. To show the applicability of proposed approach, purchasing process of Asia Pishro Diesel Company was studied as a case study.

Deshmukh and Sunnapwar (2013) identified the critical green manufacturing factors considered during supplier selection in the Indian manufacturing sector. The relationship between green supplier selection management practices and environmental performance was studied. The criteria were differentiated for evaluating traditional suppliers and green suppliers. The major activities of the green supply chain; namely green procurement, green manufacturing, green costs, quality, green packaging, customer co-operation were being covered throughout the research. From these above factors best factors for green supplier selection were selected and which could be implemented in any individual manufacturing industry. In this study, factor analysis was done to help decision makers understand the important environmental dimensions. The study demonstrated use of factor analysis to evaluate the relative importance of various environmental performance measures. This study also aimed to develop a decision support tool which should help companies to integrate environmental criteria into their green supplier selection process. Bali et al. (2013) proposed an integrated multi-criteria decision-making (MCDM) approach based on intuitionistic fuzzy set (IFS) and grey relational analysis (GRA) for green supplier selection. Because of the vagueness and imprecision of decision makers' evaluations and subjectivity of the criteria, IFS and GRA were exploited to handle these uncertainties. The analyses of the results showed that fuzzy set theory and grey theory could be used jointly for green supplier selection problems in uncertain environments.

Haldar et al. (2014) developed a quantitative approach for strategic supplier selection under fuzzy environment in a disaster scenario. This paper presented an integrated fuzzy group decision making approach based on a fuzzy technique for order preference by similarity to the ideal solution integrated with the aggregate fuzzy weight method to rank the suppliers of a manufacturing system. Using this approach, organizations could devise resiliency plans to alleviate the vulnerability of a supply chain system.

Haldar et al. (2012) incorporated an analytical framework for supply chain design, which could help the decision makers to select a suitable supplier under a disruption scenario. The supplier’s weights were initially determined using the TOPSIS and AHP methodology for general selection criteria. A cut-off value for the supplier weight was assigned and the suppliers which were above this cut-off value were selected for the primary selection process. Using AHP-QFD methodology the manufacturer's critical criteria and resiliency criteria were integrated into the selection process, to determine the subjective factor measures (SFM) for each of the primary selected suppliers. Different cost factors were unified using a normalizing technique to determine the objective factor measure (OFM) for each of the suppliers. Finally, a supplier selection index was calculated in which the decision maker's attitude plays an important role.

1.3 Motivation and Objectives

Previous section illustrates prior state of art on various aspects of performance appraisement in relation to traditional, green, flexible as well as resilient supply chain management. The importance of effective supplier selection towards enhancing supply chain's overall performance has been highlighted too. In course of assessing performance extent of a particular supply chain, at an organizational level, important evaluation measures and metrics (performance indicators/indices) need to be identified properly. Hence, it is felt that an integrated criteria-hierarchy indeed needs to be conceptualized in relation to a particular supply chain philosophy (green, agile, flexible, and resilient) by considering specific and appropriate performance dimensions. Supply chain performance appraisement frameworks have been developed by pioneer researchers; mostly focusing on traditional supply chain. But, today's global economy necessitates reengineering of traditional supply chain network by embracing modern concepts of agility, greenness, flexibility as well as resilience to satisfy a variety of global market needs. Thus, appropriate performance dimensions need to be considered in evaluating supply chain's overall performance.

Supply chain performance assessment seems a difficult task due to subjectivity of evaluation indices. These indices are basically ill-defined and vague in nature; therefore, assessment is to be made by the decision-makers. Since subjective human judgment bears ambiguity as well as vagueness; traditional tools and techniques which are based on objective data, fail to solve this problem. Literature highlights application of fuzzy set theory/fuzzy logic in solving a variety of decision-making problems where subjective evaluation information is mostly involved. Fuzzy set theory can effectively deal with imprecise and uncertain human judgment by converting those subjective data into an appropriate fuzzy-mathematic base and thus facilitates in appropriate decision-making.

The present work intends to examine application potential of various fuzzy based decision support systems towards appraisement and benchmarking of overall performance extent in relation to the organizational supply chain. Different supply chain constructs like traditional, green, flexible and resilient supply chains have been studied. The current business needs for adapting modern concepts of supply chain greenness; flexibility and resiliency have been articulated. Apart from exploring fuzzy set theory, application feasibility of grey numbers set theory have been examined towards performance benchmarking of alternative industries operating under similar supply chain construct. The work also aims to identify ill-performing supply chain areas (performance barriers) which require future improvement in order to boost up overall performance level of the particular supply chain. The work also attempts to determine a fuzzy-based quantitative performance metric reflecting overall supply chain flexibility as well as resilience.

The study has been further extended to develop efficient decision support systems to facilitate evaluation and selection of potential suppliers in green as well as resilient supply chain contexts.

Based on the literature review, following research gaps have been identified and pointed out below.

1. Lack of logical construct consisting of capabilities-attributes as well as criterions (integrated criteria-hierarchy) to assess green, flexible as well as resilient supply chain performance extent in industrial perspectives.
2. Lack of systematic framework (mathematic base) to quantify overall supply chain performance extent (quantitative metric).
3. Subjective assessment of supply chain performance extent is generally vague in nature. Because, most of the performance measures and metrics are ill-defined that need to be assessed by the decision-makers. Subjective human judgment often bears uncertainty as well as imprecision, and hence, decision-making appears very difficult.
4. Application potential of fuzzy/grey numbers set theory to facilitate supply chain performance appraisement and related decision-making.
5. Lack of an efficient Decision Support System (DSS) to help supplier selection in resilient supply chain.
6. Lack of systematic approach in identifying ill-performing supply chain entities (barriers) which require future improvement in order to boost up overall supply chain’s performance.

Objectives of the present work have been highlighted below.

1. Estimation of a unique quantitative metric to highlight overall performance extent of the supply chain. In this context, different supply chain strategies (traditional, green, flexible as well as resilience) have individually been considered.
2. Performance benchmarking of candidate industries operating under similar supply chain construct (criteria-hierarchy).
3. Exploration of fuzzy as well as grey numbers set theory in order to overcome ambiguity and vagueness in assessing ill-defined (subjective) performance indices.
4. To support fuzzy embedded decision support systems towards evaluation and selection of potential suppliers in green as well as resilience supply chain.
5. To consider decision-makers' risk bearing attitude in developing efficient decision support systems.
6. To execute empirical research as well as case study to examine procedural steps of different decision support modules like Grey-MOORA, Fuzzy-MOORA, IVFN-TOPSIS, Fuzzy-Grey Relation Method, Fuzzy-VIKOR etc. towards facilitating supply chain performance appraisement as well as effective supplier selection.

1.4 Organization of the Present Dissertation

The dissertation has been organized in the following pattern:

Chapter 1 (Background and Rationale): This chapter provides an introduction of supply chain (traditional, green, flexible and resilient supply chain), highlights the need for supply chain performance assessment and emphasizes on effective supplier selection as a key strategic consideration towards building an efficient supply chain; and consequently achieving high performance extent. Based on an extensive literature review; existing research gaps have been identified and the specific objectives of the present work have been articulated.

Chapter 2 (Supply Chain Performance Appraisement and Benchmarking: Emphasis on Traditional Supply Chain): This chapter explores an integrated criteria-hierarchy (evaluation index system) for performance appraisement of the traditional supply chain in view of candidate industries. This chapter applies (i) Grey-MOORA and (ii) Fuzzy-MOORA for performance benchmarking of candidate industries running under similar supply chain construct.

Chapter 3 (Performance Benchmarking of Green Supply Chain): In this chapter, a decision-making scenario has been conceptualized for benchmarking of 'green' performance of alternative industries operating under similar green initiatives (green supply chain constructs). Two decision-making approaches: (i) IVFN-TOPSIS and (ii) Fuzzy-grey relation method have been used to facilitate the said decision-making.

Chapter 4 (Green Supplier Selection): In this chapter, an empirical study has been carried out on supplier selection in green supply chain. A fuzzy based Multi-Level Multi-Criteria Decision Making (FMLMCDM) approach has been explored and compared with Fuzzy-TOPSIS to facilitate green supplier selection.

Chapter 5 (Performance Evaluation of Flexible Supply Chain): This chapter exhibits results of a case study in view of supply chain flexibility assessment in an industrial context. A structured criteria-hierarchy (assessment platform) has been developed considering various flexibility dimensions (evaluation indices) and a fuzzy based decision support system has been proposed for evaluating a quantitative metric for supply chain flexibility.

Chapter 6 (Performance Evaluation of Resilient Supply Chain): In this chapter, an industrial case study has been reported with the unified aim to evaluate resilient performance of organizational supply chain. An evaluation index system consisting of supply chain's resilient performance criterions has been proposed here and an efficient fuzzy based decision support module has been developed towards performance appraisement of resilient supply chain.

Chapter 7 (Resilient Supplier Selection): Based on a case empirical research, this chapter exhibits application potential of Fuzzy-VIKOR (in comparison with Fuzzy-TOPSIS) towards evaluation and selection of resilient suppliers.

Chapter 8 (Summary and Contributions: Scope for Future Work): This chapter provides executive summary of the entire work and highlights specific contributions to the extent body of past research in the field of supply chain management. Limitations of the present work have been pointed out with reference to the future scope of work.

The chronology of the work reported in this dissertation has been shown as a block diagram in Fig. 1.1.

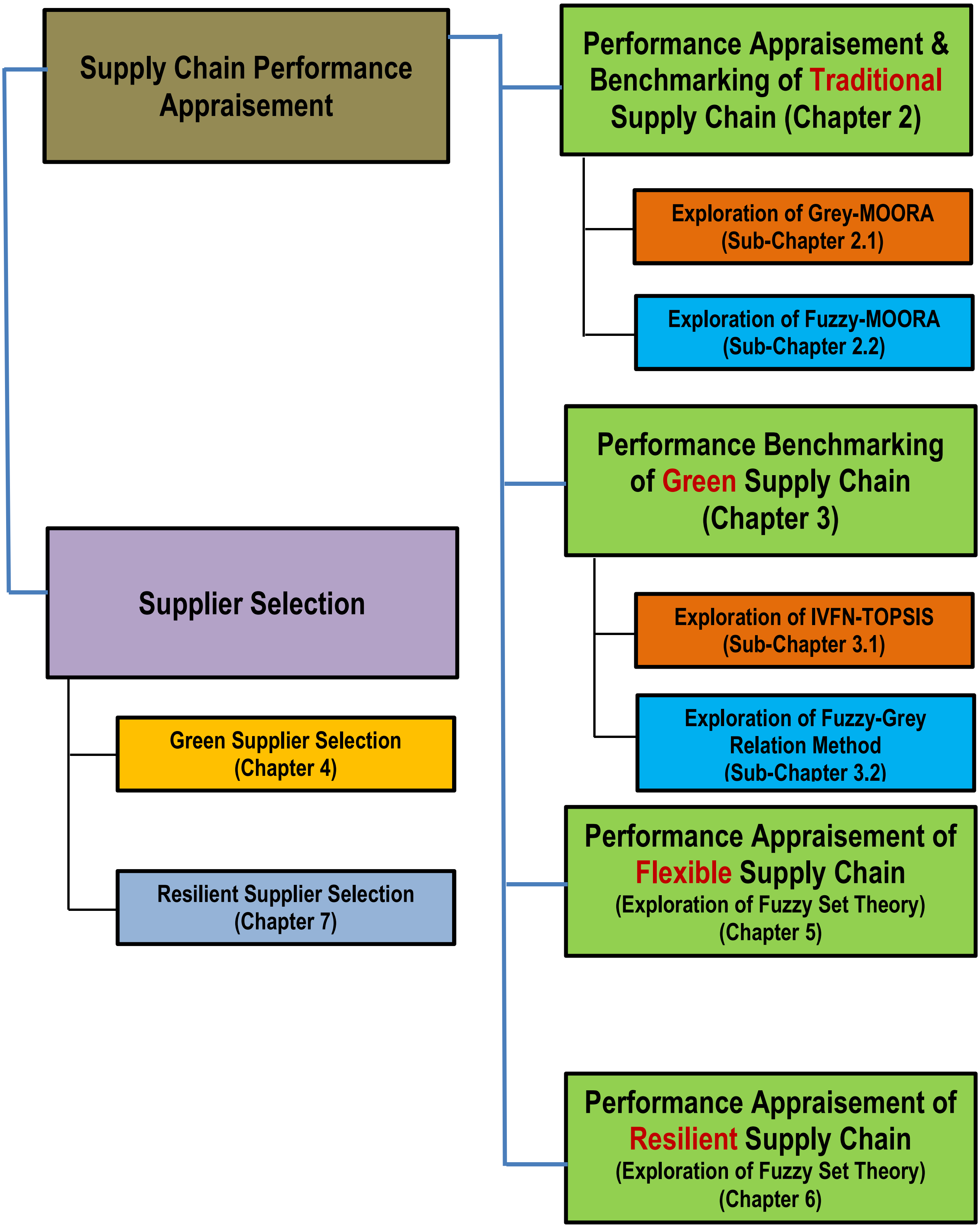

Fig. 1.1: Outline of the work carried out in the dissertation

CHAPTER 2

SUPPLY CHAIN PERFORMANCE APPRAISEMENT AND BENCHMARKING: EMPHASIS ON TRADITIONAL SUPPLY CHAIN

2.1 Supply Chain Performance Benchmarking: Exploration of Grey-MOORA

2.1.1 Coverage

In today's competitive global marketplace, performance management has been identified as a key strategic consideration towards achieving an efficient supply chain management. Supply chain performance appraisement provides necessary means by which an organization can assess whether its supply chain is performing well; whether, it has been improved or degraded as compared to the past record. The task of estimating supply chain performance extent is seemed a complex problem involved with multiple subjective performance measures and metrics; subjected to decision-making environment which carries an inherent vagueness, inconsistency and incompleteness associated with decision-makers (expert panel) commitment towards assessment of various subjective (qualitative) evaluation indices. Consequently, it becomes difficult towards making a comparative study on performances of alternative supply chains. It is therefore, indeed essential to conceptualize and develop an efficient appraisement platform helpful for benchmarking of alternative supply chains based on their performance extent.

The purpose of this research is to develop and to empirically test a multiple-indices hierarchical appraisement model for benchmarking of supply chain performance and its impact on competitiveness of manufacturing industries. The work explores the concept of grey numbers combined with MOORA (Multi-Objective Optimization by Ratio Analysis) in perspective of evaluating best alternative from among available alternative supply chains. The method has been found fruitful to facilitate such a Multi-Criteria Group Decision-Making (MCGDM) problem under uncertain environment and provides an appropriate compromise ranking order with respect to available possible alternatives.

2.1.2 Problem Definition: Application Potential of MCDM Techniques

An exhaustive literature survey has been conducted to realize an understanding of prior state of art. Contributions of the past research have been summarized below; based on which the research gap has been identified and the current problem has been formulated.

Beamon (1999) presented a framework towards selection of performance measurement systems for manufacturing supply chains. Brewer and Speh (2000) described the importance of balance score card with respect to supply chain performance measurement. Gunasekaran et al.

(2001) developed a framework for measuring strategic, tactical and operational level performances in a supply chain. Lau et al. (2002) proposed a frame work of supply chain management embracing the principles of fuzzy logic for analyzing and monitoring performances of suppliers based on the criteria of product quality and delivery time.

Chan (2003) explored Analytic Hierarchy Process (AHP) to make decisions based on the priority of performance measurement indices. Perona and Miragliotta (2004) investigated how complexity could affect a manufacturing company's performances, and its supply chain. A model was suggested to control complexity within manufacturing and logistics systems could be regarded as a core competence in order to jointly improve efficiency and effectiveness at a supply chain wide scale. Agarwal and Shankar (2005) provided an effective framework for analyzing different performance metrics affecting supply chain performance. Shepherd and Günter (2006) pointed out the factors influencing successful implementation of performance measurement systems for supply chains; provided taxonomy of measures. Bhagwat and Sharma (2007) developed a balanced scorecard for supply chain management (SCM) that measured and evaluated day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and balanced scorecard. Kamalabadi et al. (2008) presented a supply chain performance measurement by using of FMADM (Fuzzy Multi-Attribute Decision Making) approach. Tao (2009) combined improved entropy method and fuzzy matter-element theory to establish a fuzzy-matter model for evaluating supply chain performance.

Shaw et al. (2010) provided the direction for practitioners on measuring the environmental impact of supply chains in the context of the overall business performance. Cuthbertson and Piotrowicz (2011) demonstrated an approach for analyzing existing supply chain performance measurement systems that applied across different supply chains and sectors. The authors created an opportunity to use a consistent data collection process across a variety of supply chain situations and thus generated data for further theory development.

Geethan et al. (2011) developed performance evaluation analytic for reverse logistics methodology to facilitate decision-making from the perspective of an enterprise engaged in reverse logistics. It also developed some key business strategies and performance metrics that employed to be successful in returns handling reverse supply chain. Prasad (2012) identified seven performance dimensions (cost, quality, time, productivity, flexibility, reliability, and customer service) to measure supply chain performance.

MOORA (multi objective optimization by ratio analysis) method, a newly developed MCDM tool documented in literature; has shown immense popularity in facilitating complex decision scenarios.

Stanujkic et al. (2012) presented an algorithm by extended the MOORA method for solving decision making problems with interval data to determine the most preferable alternative among all possible alternatives, when performance ratings were given as intervals. Chakraborty (2011) explored the application of MOORA method to solve different decision making problems as frequently encountered in the real-time manufacturing environment. Gadakh (2011) applied MOORA method for solving multiple criteria (objective) optimization problem in milling process. Kalibatas and Turskis (2008) explored MOORA towards solving the inner climate problems. Kildiene (2013) proposed MULTIMOORA method for assessment of opportunities for construction enterprises in European Union member states. A theory of dominance compared three parts: the ratio system, the reference point and the full multiplicative form. Countries were ranked according to suitability of their environment for business. Kracka et al. (2010) applied the MOORA method in construction in order to solve problems related to energy loss in heating buildings.

Simple MOORA method takes into consideration of numeric evaluation data. Later MOORA method has been extended to be operated in fuzzy environment to tackle subjective evaluation information. Fuzzy logic is used where data is uncertain full of ambiguity as well as vagueness.

Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world. Additional benefits of fuzzy logic include its simplicity and its flexibility. Fuzzy logic can handle problems with imprecise and incomplete data,

[Source: http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol2/jp6/article2.html]

Fuzzy Logic is one of the best tools to model the imprecise and the blurred world. The real world is too complicated for precise descriptions to be obtained; therefore, approximations (or fuzziness) must be introduced in order to obtain a reasonable, yet traceable, model (Wang 1997). Fuzzy logic is the tool for transforming human knowledge and its decision-making ability into a mathematical formula. In other words, it provides with meaningful and powerful representation of measurement uncertainties and also with meaningful representation of vague concepts expressed in natural language (Klir and Yuan, 1995).

Baležentis et al. (2012) aimed at extending the fuzzy MULTIMOORA for linguistic reasoning under group decision making for personnel selection. A numerical example exhibited the possibilities for improvement of human resource management as well as any other business decision area by applying MULTIMOORA–FG. Brauers and Zavadskas (2006) proposed MOORA which was applied to solve many economic, managerial and construction problems. Balezentis and Zeng (2013) explored extended MULTIMOORA method with type-2 fuzzy sets viz. generalized interval-valued trapezoidal fuzzy numbers. A numerical example of personnel selection demonstrated the possibilities of application of the proposed method in the field of human resource management and performance management in general.

Apart from fuzzy logic, it is felt that grey theory (Yang and Li, 2011; Liu et al., 2012) can also be integrated with MOORA concept to facilitate a variety of decision-making problem solutions.

Grey analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown.

[Source: http://en.wikipedia.org/wiki/Grey_relational_analysis]

To this end, present study aims at adapting grey theory as well as MULTIMOORA method in order to develop an efficient performance appraisement module towards evaluation, selection and benchmarking of supply chain performance extent. Integrated criteria hierarchy (consisting of 4-level evaluation indices) has been transformed into single layer of evaluation criterions, using grey-mathematics which utilizes performance ratings as well as priority weights of individual evaluation indices at various level of criteria-hierarchy. Then, grey interval-value embedded with MULTIMOORA method has been applied to obtain a feasible ranking order of performance extent of alternative supply chains.

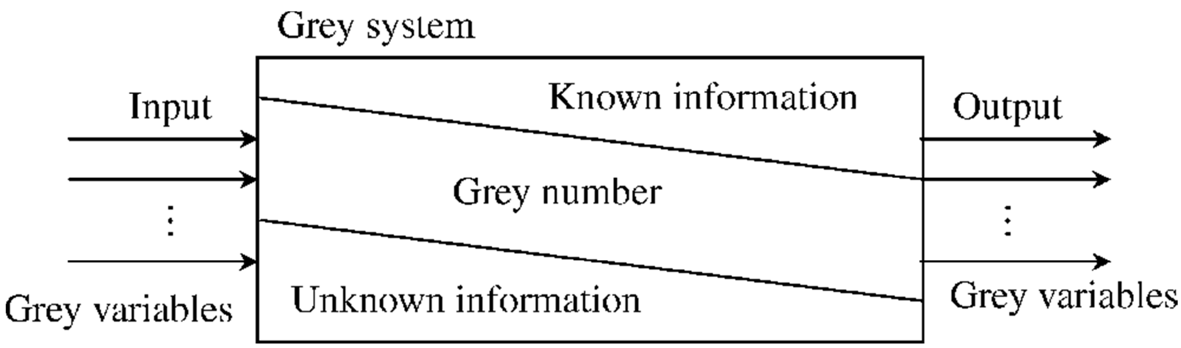

Fig. 2.1: The concept of a grey system

2.1.3 Theory of Grey Numbers: Mathematical Basis

Grey theory (Deng, 1982), originally developed by *Prof. Deng* in 1982, has become a very effective method of solving uncertainty problems under discrete data and incomplete information. Grey theory has now been applied to various areas such as forecasting, system control, decision-making, computer graphics and many others. Here, some basic definitions regarding relevant mathematical background of grey system, grey set and grey number in grey theory have been presented below.

Definition 1: A grey system (Xia, 2000) is defined as a system containing uncertain information presented by grey number and grey variables. The concept of grey system is shown in Fig. 2.1.

Definition 2: Let X be the universal set. Then a grey set G of X is defined by its two mappings

$$\begin{cases} \overline{\mu}_G(x):\ x \rightarrow [0,1] \\ \underline{\mu}_G(x):\ x \rightarrow [0,1] \end{cases} \tag{2.1}$$

$\overline{\mu}_G(x) \geq \underline{\mu}_G(x), x \in X,\ X = R,\ \overline{\mu}_G(x)$ and $\underline{\mu}_G(x)$ are the upper and lower membership functions in G respectively. When $\overline{\mu}_G(x) = \underline{\mu}_G(x)$, the grey set G becomes a fuzzy set. It shows that grey theory considers the condition of fuzziness and can flexibly deal with the fuzziness situation.

Definition 3: A grey number is one of which the exact value is unknown, while the upper and/or the lower limits can be estimated. Generally grey number is written as $\left(\otimes G = G\big|_{\underline{\mu}}^{\overline{\mu}}\right)$.

Definition 4: If only the lower limit of G can be possibly estimated and G is defined as lower limit grey number.

$$\otimes G = [\underline{G}, \infty] \tag{2.2}$$

Definition 5: If only the upper limit of G can be possibly estimated and G is defined as lower limit grey number.

$$\otimes G = [-\infty, G] \tag{2.3}$$

Definition 6: If the lower and upper limits of G can be estimated and G is defined as interval grey number.

$$\otimes G = [\underline{G}, \overline{G}] \tag{2.4}$$

Definition 7: The basic operations of grey numbers $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ can be expressed as follows:

$$\left.\begin{aligned} &\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2,\ \overline{x}_1 + \overline{x}_2] \\ &\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \underline{x}_2,\ \overline{x}_1 - \overline{x}_2] \\ &\otimes x_1 \times \otimes x_2 = [\underline{x}_1 \underline{x}_2,\ \overline{x}_1 \overline{x}_2] \\ &\otimes x_1 \div \otimes x_2 = [\underline{x}_1, \overline{x}_1] \times \left[\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}\right] \end{aligned}\right\} \tag{2.5}$$

Whitened value: The whitened value of an interval grey number, $\otimes x$ is a deterministic number with its value lying between the upper and lower bounds of interval $\otimes x$. For a given interval grey number $\otimes x = [\underline{x}, \overline{x}]$ the whitened value $x_{(\lambda)}$ can be determined as follows (Liu and Lin, 2006):

$$x_{(\lambda)} = \lambda \underline{x} + (1-\lambda)\overline{x}, \tag{2.6}$$

Here, λ as whitening coefficient and $\lambda \in [0,1]$. Because of its similarity with a popular λ function, Eq. 2.6 is often shown in the following form:

$$x_{(\lambda)} = (1-\lambda)\underline{x} + \lambda \overline{x} \tag{2.7}$$

For $\lambda = 0.5$ Eq. 2.7 gets the following form:

$$x_{(\lambda=0.5)} = \frac{1}{2}(\underline{x} + \overline{x}) \tag{2.8}$$

Signed distance: Let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be two positive interval grey numbers. Then, the distance between $\otimes x_1$ and $\otimes x_2$ can be calculated as signed difference between its centers (Eberly, 2007) is shown below:

$$d(\otimes x_1, \otimes x_2) = \frac{\underline{x}_1 - \overline{x}_1}{2} - \frac{\underline{x}_2 - \overline{x}_2}{2} = \frac{1}{2}[(\underline{x}_1 - \underline{x}_2) + (\overline{x}_1 - \overline{x}_2)] \tag{2.9}$$

2.1.4 The MOORA Method

Multi-Objective Optimization by Ratio Analysis (MOORA) method was introduced by Brauers and Zavadskas (2006) on the basis of previous researches (Brauers 2004). The method starts with a matrix of responses of different alternatives on different objectives:

$$X = [x_{ij}]_{m \times n} \tag{2.10}$$

Here, x_{ij} as the response of alternative j on objective or attribute i; $i = 1,2,...,n;$ as the objectives or the attributes; and $j = 1,2,...,m$ as the alternatives.

The MOORA method consists of two parts: (i) *The Ratio system* and (ii) *The Reference point approach* (Brauers and Zavadskas, 2010; 2011).

2.1.4.1 The Ratio System Approach of the MOORA Method

Brauers and Zavadskas (2006) proved that the most robust choice for denominator is the square root of the sum of squares of each alternative per objective, and therefore the use of vector normalization method is recommended in order to normalize responses of alternatives. As a result, the following formula proposed by (Delft and Nijkamp, 1977) is used:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^{2}}} \tag{2.11}$$

Here, x_{ij} as the response of alternative j on objective or attribute i; $j = 1,2,...,m;$ m the number of alternatives; $i = 1,2,...,n;$; n the number of objectives; x_{ij}^{*} as normalized response of alternative j on objective i ; and $x_{ij}^{*} \in [0,1]$.

For optimization based on the *Ratio System Approach* of MOORA method, normalized responses are added in case of maximization and subtracted in case of minimization, which can be expressed by the following formula**:**

$$y_{j}^{*} = \sum_{i=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{i=n} x_{ij}^{*}, \tag{2.12}$$

Here, x_{ij}^{*} as normalized response of alternative j on objective i; $i=1,2,...,g;$ as the objectives to be maximized; $i=g+1, g+2,....., n;$ as the objectives to be minimized $j=1,2,...,m;$ as the alternatives; and y_{j}^{*} as the overall ranking index of alternative j $y_{j}^{*} \in [-1,1]$.

After that, the optimal alternative based on the ratio system part A_{RS}^{*} can be determined using the following formula:

$$A_{RS}^{*} = \left\{ a_j \,\middle|\, = \max_j y_j^{*} \right\} \tag{2.13}$$

2.1.4.2 The Reference Point Approach of the MOORA Method

The Reference Point Approach of the MOORA method is based on the Ratio system and starts from already normalized responses of alternatives, obtained by (Eq. 2.11). After considering the most important reference point metrics, Brauers and Zavadskas (2006, 2010, 2011), Brauers et al. (2008) and Brauers (2008) emphasized that the min-max metric is the best choice among all of them. Therefore, for optimization based on the reference point approach Brauers and Zavadskas (2006) proposed the following formula:

$$\min_j \left\{ \max_i \left| r_i - x_{ij}^{*} \right| \right\} \tag{2.14}$$

Here, r_i as i^{th} coordinate of the reference point; x_{ij}^{*} as the normalized response of alternative j on objective i; $i=1,2,...,n;$ as the objectives; and $j=1,2,...,m;$ as the alternatives.

For further simpler presentations, we will mark distance from an alternative to the reference point with d and therefore, Eq. 2.14 gets the following form:

$$\min_j \quad \max_i \; d_{ij} \tag{2.15}$$

Here, $d_{ij} = \left| r_i - x_{ij}^{*} \right|$; and (2.16)

$$r_i = \begin{cases} \max\limits_j x_{ij}^* & \text{for objectives to be maximized} \\ \\ \min\limits_j x_{ij}^* & \text{for objectives to be minimized} \end{cases} \tag{2.17}$$

Here, x_{ij}^* as the normalized response of alternative j on objective i; r_i as i^{th} coordinate of the reference point; d_{ij} as unsigned distance of alternative j to the i^{th} coordinate of reference point; $i = 1,2,..., n$; as the objectives; and $j = 1,2,..., m$ as the alternatives.

Based on the Reference point approach of the MOORA method, the optimal alternative A_{RP}^* can be determined using the following formula:

$$A_{RP}^* = \left\{ a_j \middle| = \min_j \ \max_i \ d_{ij} \right\} \tag{2.18}$$

2.1.4.3 The Importance Given to Objectives

When solving real-world problems using MCDM methods, objectives do not always have the same importance, i.e. some objectives are more important than the others. In order to give more importance to an objective, it could be multiplied with a Significance Coefficient (Brauers and Ginevicius, 2009). Importance given to objectives has influence on *Ratio System* and *Reference Point Approach* of the MOORA method. In *Ratio System Approach* importance given to objectives is included by modifying (Eq. 2.12) which assumes the following form:

$$\ddot{y}_j^* = \sum_{i=1}^{g} s_i x_{ij}^* - \sum_{i=g+1}^{i=n} s_i x_{ij}^*, \tag{2.19}$$

Here, s_i as significance coefficient of objective i; $i = 1,2,..., g$; as the objectives to be maximized; $i = g+1, g+2,....., n$; as the objectives to be minimized; $j = 1,2,..., m$; as the alternatives; and $\ddot{y}_j^*$ as the overall ranking index of alternative j with respect to all objectives with significance coefficients, $\ddot{y}_j^* \in [-1,1]$.

After that, the (Eq. 2.13) still remains to determine the most appropriate alternative based on Ratio System Approach of the MOORA method.

As the most effective way to include importance given to objectives into Reference Point Approach of MOORA method, Stanujkic et al. (2012) proposed to adopt Eq. 2.16, which after adoption gets the following form:

$$d_{ij} = s_i \left| r_i - x_{ij}^* \right|; \tag{2.20}$$

Here, s_i as significance coefficient of objective i; x_{ij}^* as the normalized response of alternative j on objective i; r_i as i^{th} coordinate of the reference point; d_{ij} as distance of alternative j to the i^{th} coordinate of reference point; $i = 1,2,..., n$; as the objectives; and $j = 1,2,..., m$; as the alternatives.

After that, the (Eq. 2.18) still remains without changes for determining the most appropriate alternative based on the Reference point approach of the MOORA method.

2.1.5 The Grey-MOORA

The procedure of selecting the most appropriate alternative using MOORA method involves several important stages that should be considered before an extension of the MOORA method with interval grey numbers, and these are:

Stage 1: Transforming responses of alternatives into dimensionless values;

Stage 2: Determining overall ranking indices for considered alternatives based on Ratio System part of MOORA method; and

Stage 3: Determining distances between considered alternatives and reference point based of the Reference Point Part of the MOORA method.

The procedural steps involved in Grey-MOORA method has been summarized below.

Stage 1: Transformation into dimensionless values

For the normalization of responses of alternatives expressed in the form of interval numbers, Jahanshahloo et al. (2006) suggested the use of the following formula:

$$\otimes x_{ij}^{*} = \frac{\otimes x_{ij}}{\sqrt{\sum_{j=1}^{m}(\underline{x}_{ij}^{2} + \overline{x}_{ij}^{2})}} \tag{2.21}$$

Eq. 2.21 provides the appropriate form for normalizing responses of alternatives expressed by interval grey numbers. However, in cases of multi-criteria optimizations which require simultaneously the use of crisp and interval grey numbers, the previously mentioned formula give unsatisfactory results. Therefore, the use of the following formula is suggested:

$$\otimes x_{ij}^{*} = \frac{\otimes x_{ij}}{\sqrt{\frac{1}{2}\sum_{j=1}^{m}(\underline{x}_{ij}^{2} + \overline{x}_{ij}^{2})}} \tag{2.22}$$

Based on Eq. 2.22, upper and lower bounds of an interval grey number can be determined using the following formulae:

$$\overline{x}_{ij}^{*} = \frac{\overline{x}_{ij}}{\sqrt{\frac{1}{2}\sum_{j=1}^{m}(\underline{x}_{ij}^{2} + \overline{x}_{ij}^{2})}} \tag{2.23}$$

$$\underline{x}_{ij}^{*} = \frac{\underline{x}_{ij}}{\sqrt{\frac{1}{2}\sum_{j=1}^{m}(\underline{x}_{ij}^{2} + \overline{x}_{ij}^{2})}} \tag{2.24}$$

Stage 2: Determining overall ranking index based on *Ratio System Approach* of the MOORA method

For optimization based on the *Ratio System Approach* of the MOORA method, starting from the formula:

$$y_{j}^{*} = y_{j}^{+} - y_{j}^{-}, \tag{2.25}$$

Here, $y_{j}^{+} = \sum_{i \in \Omega_{C}^{+}} s_i\, x_{ij}^{*} + \sum_{i \in \Omega_{G}^{+}} \otimes s_i\, x_{ij}^{*},$ (2.26)

$$y_{j}^{-} = \sum_{i \in \Omega_{C}^{-}} s_i\, x_{ij}^{*} + \sum_{i \in \Omega_{G}^{-}} \otimes s_i\, x_{ij}^{*}, \tag{2.27}$$

Here, y_j^* as the overall ranking index of alternative j; y_j^+ and y_j^- as total sums of maximizing and minimizing responses of alternative j to objectives respectively; s_i as significance coefficient of objective i; x_{ij}^* and $\otimes x_{ij}^* \ldots$ as the normalized responses of alternative j on different objectives, which are expressed in the form on crisp or interval grey numbers; $\Omega_{\underset{C}{+}}$ and $\Omega_{\underset{G}{+}}$ as the sets of objectives to be maximized expressed in the form on crisp or interval grey numbers; $\Omega_{\underset{C}{-}}$ and $\Omega_{\underset{G}{-}}$ are sets of objectives to be minimized expressed in the form on crisp or interval grey numbers. By replacing Eq. 2.26 and Eq. 2.27, in Eq. 2.25, the following formula is obtained:

$$y_j^* = \sum_{i \in \Omega_C^+} s_i x_{ij}^* - \sum_{i \in \Omega_C^-} s_i x_{ij}^* + \sum_{i \in \Omega_G^+} \otimes s_i x_{ij}^* - \sum_{i \in \Omega_G^-} \otimes s_i x_{ij}^*, \tag{2.28}$$

Based on the Eq. 2.28, Eq. 2.7 and Eq. 2.9, the final and complete formula is obtained as shown below.

$$\begin{aligned} y_j^* = \sum_{i\in\Omega_C^+} s_i x_{ij}^* - \sum_{i\in\Omega_C^-} s_i x_{ij}^* + (1-\lambda)\left(\sum_{i\in\Omega_G^+} s_i \underline{x}_{ij}^* - \sum_{i\in\Omega_G^-} s_i \underline{x}_{ij}^*\right) + \\ \lambda\left(\sum_{i\in\Omega_G^+} s_i \overline{x}_{ij}^* - \sum_{i\in\Omega_G^-} s_i \overline{x}_{ij}^*\right) \end{aligned} \tag{2.29}$$

Here, s_i as significance coefficient of objective i; x_{ij}^* as the normalized responses of alternative j on objective i and $i \in \Omega_C$; $\underline{x}_{ij}^*$ and $\overline{x}_{ij}^*$ as the normalized bounds of interval grey number which represents response of alternative j on objective i and $i \in \Omega_G$, respectively; Ω_C and Ω_G as the sets of objectives expressed in the form of crisp or interval grey numbers, respectively; λ as the whitening coefficient; y_j^* as the overall ranking index of alternative j; $\Omega_{\underset{C}{+}}$ and $\Omega_{\underset{G}{+}}$ as the sets of objectives to be maximized expressed in the form on crisp or interval grey numbers; $\Omega_{\underset{C}{-}}$ and $\Omega_{\underset{G}{-}}$ are sets of objectives to be minimized expressed in the form on crisp or interval grey numbers; $i = 1,2,..., n$; as the objectives; and $j = 1,2,..., m$; as the alternatives.

In the case of solving complex real-world problems that require simultaneous use of crisp and interval grey numbers, Eq. 2.29 provides adequate ability to rank and select the most appropriate alternative.

In the case of solving well-structured problems, the second part of Eq. 2.29 which includes the impact of objectives whose responses are expressed using interval grey numbers, has no influence on ranking index and therefore, Eq. 2.29 can be transformed into following forms:

$$y_j^* = \sum_{i \in \Omega_C^+} x_{ij}^* - \sum_{i \in \Omega_C^-} x_{ij}^* \text{; or} \tag{2.30}$$

$$y_j^* = \sum_{i \in \Omega_C^+} s_i\, x_{ij}^* - \sum_{i \in \Omega_C^-} s_i\, x_{ij}^* \tag{2.31}$$

The case, when objectives have different significances, Eq. 2.31 is employed. The (Eqs. 2.30-2.31) have same meanings as (Eqs. 2.12 and 2.19), respectively, in original MOORA method.

On the other hand, in the case of solving semi-structured problems, the first part of Eq. 2.29, which represents the impact of objectives whose responses are expressed by crisp numbers, has no influence to the overall ranking index and therefore, it can be transformed into one of three following forms:

i. When objectives have the same significance:

$$y_j^* = (1-\lambda)\left(\sum_{i \in \Omega_G^+} \underline{x}_{ij}^* - \sum_{i \in \Omega_G^-} \underline{x}_{ij}^*,\right) + \lambda\left(\sum_{i \in \Omega_G^+} \overline{x}_{ij}^* - \sum_{i \in \Omega_G^-} \overline{x}_{ij}^*,\right) \tag{2.32}$$

ii. When the decision maker has no preferences $(\lambda = 0.5)$

$$y_j^* = \frac{1}{2}\left(\sum_{i \in \Omega_G^+} s_i\, \underline{x}_{ij}^* - \sum_{i \in \Omega_G^-} s_i\, \underline{x}_{ij}^*,\right) + \frac{1}{2}\left(\sum_{i \in \Omega_G^+} s_i\, \overline{x}_{ij}^* - \sum_{i \in \Omega_G^-} s_i\, \overline{x}_{ij}^*,\right) \tag{2.33}$$

iii. When the decision maker has no preference and objectives have the same significance:

$$y_j^* = \frac{1}{2}\left(\sum_{i \in \Omega_G^+} \underline{x}_{ij}^* - \sum_{i \in \Omega_G^-} \underline{x}_{ij}^*,\right) + \frac{1}{2}\left(\sum_{i \in \Omega_G^+} \overline{x}_{ij}^* - \sum_{i \in \Omega_G^-} \overline{x}_{ij}^*,\right) \tag{2.34}$$

During problem solution, i.e. ranking of alternatives, the attitude of the decision-makers can lie between pessimistic and optimistic, and the whitening coefficient λ, allows expression of decision makers degree of optimism or pessimism.

In the case of particularly expressed optimism, the whitening coefficient λ, in accordance with (Eq. 2.7), takes higher values $(\lambda \rightarrow 1)$ and ranking order of alternatives is mainly based on the upper bounds of intervals with which overall response of each alternative is expressed, $y_{j(\lambda=1)} = \overline{y}_j^*$. On the other hand, in the case of particularly expressed pessimism, the whitening coefficient λ takes lower values $(\lambda \rightarrow 0)$ and ranking order of alternatives is mainly based on lower bounds of the intervals $y_{j(\lambda=0)} = \overline{y}_j^*$.

Stage 3: Determining overall ranking index based on Reference Point Approach of the MOORA method

The most appropriate alternative based on the Reference Point Approach of the MOORA method, when ratings of alternatives are expressed using exact values can be obtained by the Eq. 2.15. However, this formula should be adopted in the case when the Reference Point Approach of the MOORA method is used to solve complex real-world problems. To explain the approach in detail, starting from the min-max metric expressed by the formula:

$$\min_{j} \quad \max_{i} \; d_{ij} \qquad (2.35)$$

Here, d_{ij} as distance of alternative j to the i^{th} coordinate of reference point.

In the course of solving many complex real-world problems, responses to the objectives are simultaneously expressed using crisp and interval grey numbers. In this case, the reference point cannot be expressed adequately with 'simple' point in n-dimensional space. It is believed that the reference grey point is a more appropriate solution, where coordinates of grey reference point may be crisp or interval grey numbers, depending on type of values which is used to express ratings of alternatives to the corresponding objectives. Therefore, for determining d_{ij} and r_i for objective i in different cases, (Stanujkic et al., 2012) proposed the following:

i. For objective i with crisp responses, the correspondent coordinate of the reference grey point is calculated using the Eq. 2.17 and distance to the reference point using Eq. 2.16 or Eq. 2.20 when objectives have different significances.

ii. For objectives whose responses are expressed using interval grey numbers formulae are more complex, especially when decision makers have opportunity to express their attitudes about optimism or pessimism. For these reasons, starting from the following formulae:

$$d_{ij} = (1-\lambda)\underline{d}_{ij} + \lambda\,\overline{d}_{ij} \text{ ; or} \tag{2.36}$$

$$d_{ij} = s_i\left((1-\lambda)\underline{d}_{ij} + \lambda\,\overline{d}_{ij}\right) \tag{2.37}$$

The case, when objectives have different significances, where:

$$\underline{d}_{ij} = \left|\underline{r}_i - \underline{x}^*_{ij}\right| \text{; and} \tag{2.38}$$

$$\overline{d}_{ij} = \left|\overline{r}_i - \overline{x}^*_{ij}\right|; \tag{2.39}$$

Here, λ as whitening coefficient; $\underline{d}_{ij}$ and $\overline{d}_{ij}$ as distances of alternative j to the i^{th} coordinate of reference grey point; s_i as significance coefficient of objective i; $i = 1,2,..., n$; as the objectives; and $j = 1,2,..., m$; as the alternatives.

Every coordinate of reference grey point is represented by appropriate interval grey numbers which bounds are determined by using the following formulae:

$$\left.\begin{aligned} \overline{r}_i &= \max_j \; x^*_{ij} \\ \underline{r}_i &= \min_j \; x^*_{ij} \end{aligned}\right\} \text{for objective to be maximized; and} \tag{2.40}$$

$$\left.\begin{aligned} \overline{r}_i &= \min_j \; x^*_{ij} \\ \underline{r}_i &= \max_j \; x^*_{ij} \end{aligned}\right\} \text{for objective to be minimized;} \tag{2.41}$$

Now, depending on decision-makers' preferences, i.e. whitening coefficient value; the Eqs. 2.36-2.37 may have the following specific forms:

i. In the case of extremely pessimistic decision maker attitude, $(\lambda = 0)$**:**

$$d_{ij(\lambda=0)} = \begin{cases} \underline{d}_{ij} & \text{when objectives have the same significance; or} \\ s_i\,\underline{d}_{ij} & \text{when objectives have different significances} \end{cases} \tag{2.42}$$

ii. In the case of moderate optimism or when the decision maker has no preference, $(\lambda = 0.5)$:

$$d_{ij(\lambda=0.5)} = \begin{cases} (\underline{d}_{ij} + \overline{d}_{ij})/2 & \text{when objectives have the same significance; or} \\ s_i\,(\underline{d}_{ij} + \overline{d}_{ij})/2 & \text{when objectives have different significances.} \end{cases} \quad (2.43)$$

iii. Finally in the case of extremely optimistic decision maker attitude, $(\lambda = 1)$:

$$d_{ij(\lambda=1)} = \begin{cases} \overline{d}_{ij} & \text{when objectives have the same significance; or} \\ s_i\,\overline{d}_{ij} & \text{when objectives have different significances.} \end{cases} \quad (2.44)$$

2.1.6 Case Empirical Research

The supply chain performance evaluation index platform (Chan and Qi, 2003) adapted in this paper has been shown in (Table 2.1). Assume that there are three alternative industries which correspond to similar supply chain architecture. Our objective is to select the best one with respect to the supply chain performance. The 4-level hierarchical model consists of various indices: measures and metrics. Supply (S), Inbound Logistics (IL), Core Manufacturing (CM), Outbound Logistics (OL), Marketing and Sales (M&S) have been considered as the 1st level indices (called measures) followed by 2nd level indices, then 3rd level indices and finally the 4th level indices which encompasses numerous supply chain performance metrics. An integrated approach of MOORA combined with interval-valued grey numbers set has been explored to evaluate a supply chain performance of alternative industries. This method has been found fruitful for solving such a group decision-making problem under uncertain environment due to vagueness, inconsistency and incompleteness associated with decision-makers' subjective evaluation information. The block diagram of grey-MOORA method towards supply chain performance appraisement has been furnished in Fig. 2.2.

Empirical research has been carried out to verify application procedural steps of the proposed approach towards evaluation of supply chain performance of alternative industries under uncertain environment. Assume that a committee of five decision-makers (expert group) such as $DM_1, DM_2, DM_3, DM_4, DM_5$ has been constructed from academicians, manager of production unit, marketing unit, material purchasing unit and his/her team. Also, assume that there have been three alternative industries' supply chains such as A_1, A_2 and A_3.

In this part of work, priority weights against individual performance metrics and corresponding performance extent (appropriateness ratings) have been obtained by linguistic information, provided by the expert group; which have been further transformed into IV grey numbers. Here, these linguistic variables corresponding to weight assignment of various performance metrics (from 2^{nd} to 4^{th} level of the evaluation hierarchy; (Table 2.1), has been expressed in grey numbers by a 7-member scale as shown in (Table 2.2). Similarly, the grey performance ratings of individual evaluation metrics in 4^{th}level have also been expressed in grey numbers by a 7-member scale shown in (Table 2.2).

The procedural steps and data analysis of empirical study have been summarized as follows:

Step 1: Gathering information from the expert group in relation to performance rating and importance weights of different evaluation metrics using linguistic terms

For evaluating importance weights of numerous supply chain metrics (from 2 to 4^{th} level), as well as appropriateness rating only for 4^{th} level metrics; a committee of fives decision-makers (DMs), $DM_1, DM_2, DM_3, DM_4, DM_5$ has been assumed constructed to express their subjective preferences (evaluation score) in linguistic terms shown in (Tables 2.2) which have been further transformed into interval-valued grey numbers. The decision-makers assessing importance weights of various supply chain performance indices for alternative A_1, A_2 and A_3 have been shown in (Tables 2.3-2.5), for 4^{th} level, 3^{rd} level, and 2^{nd} level indices, respectively. This weight assignment has been made irrespective of the alternative SCs. The appropriateness rating (in linguistic terms) against individual 4^{th} level evaluation indices as assigned by the decision-makers have been furnished in (Tables 2.6-2.8), for alternative A_1, A_2 and A_3, respectively.

Step 2: Approximation of the linguistic evaluation information by IV grey numbers

Using the concept of interval-valued grey numbers in grey set theory, the linguistic variables have been transformed into corresponding appropriate grey numbers using the scale as indicated in (Table 2.2). Next, based on grey operational rule; the aggregated grey priority weights for (4^{th}level, 3^{rd} level and 2^{nd} level) have been computed irrespective of alternatives: A_1, A_2 and A_3. Similarly, aggregated performance ratings (as well as priority weights) of various 4^{th} level indices have been computed (Table 2.9). Following the backward path (starting from 4^{th} level in the evaluation hierarchy) and exploring grey 'weighted average rule'; performance ratings of different evaluation indices at preceding levels (3^{rd} level, and finally 2^{nd} level) have been computed (Tables 2.10-2.11).

Appropriateness rating (also called Grey Performance Index, GPI) for each of the 3rd level evaluation index, i.e. U_{ijk} (rating of k_{th} index) has been computed as follows:

$$GPI_k = U_{ijk} = \frac{\sum U_{ijkl} \otimes w_{ijkl}}{\sum w_{ijkl}} \qquad (2.45)$$

U_{ijkl} is denoted as the aggregated fuzzy appropriateness rating against l_{th} index (at 4th level) which is under k_{th} index in the 3rd level, under j_{th} index in the 2nd level and under i_{th} index in the 1st level. w_{ijkl} is the aggregated fuzzy weight against l_{th} index (at 4th level).

Appropriateness rating for each of the 2nd level evaluation index U_{ij} (rating of j_{th} index) has been computed as follows:

$$GPI_j = U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ijk}} \qquad (2.46)$$

U_{ijk} is denoted as the computed fuzzy appropriateness rating (obtained using Eq. 2.45) against k_{th} index (at 3rd level) which is under j_{th} index in the 2nd level and under i_{th} index in the 1st level. w_{ijk} is the aggregated fuzzy weight against k_{th} index (at 3rd level).

Appropriateness rating for each of the 1st level evaluation index U_i (rating of i_{th} index) has been computed as follows:

$$GPI_i = U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \qquad (2.47)$$

U_{ij} is denoted as the computed fuzzy appropriateness rating (obtained from Eq. 2.46) against j_{th} index (at 2nd level) which is under i_{th} index in the 1st level. w_{ij} is the aggregated fuzzy weight against j_{th} -index (at 2nd level) which is under i_{th} index at 1st level.

The computation results have been shown in subsequent table (Table 2.12), for alternative A_1, A_2 and A_3, respectively. The appropriateness rating against 1st level evaluation measures has been computed and furnished in Table 2.12, for alternative A_1, A_2 and A_3 respectively.

Step 2: Normalization

All of the indices/metric have been assumed beneficial in nature and expressed in terms of interval-valued grey numbers but usually these numbers belong to the interval [0; 1]. Hence, normalization has been carried out by employing Eqs. (2.22-2.24). The normalized matrix has been shown in Table 2.13.

For evaluating priority weights (significance) of numerous supply chain performance indices, C_1, C_2, C_3, C_4, and C_5, the committee of same decision-makers (DMs), has been expressed the significance values to each supply chain performance indices C_1, C_2, C_3, C_4, and C_5,as 0.20, 0.19, 0.17, 0.21, and 0.23, respectively.

Step 3: The Ratio System

In the Ratio System, exploring the normalized values shown in Table 2.13 and using (Eq. 2.33), the results thus obtained have been shown in (Table 2.14) and (Table 2.15). In this computation priority weight of individual evaluation measuresC_1, C_2, C_3, C_4, and C_5, (0.20, 0.19, 0.17, 0.21, and 0.23) have been considered.

Step 4: Reference Point Approach

Using the normalized values shown in Table 2.13 and using (Eqs. 2.37-2.41), coordinates of reference grey point and distances of alternatives to reference grey point have been obtained for $\lambda = 0,\ 0.5,\ 1$ (Tables 2.16-2.17). It has been shown that the ranking order of alternative industries (in view of ongoing supply chain performance extent) appears same (A_3> A_1> A_2) for both the Ratio System Part as well as Reference Point Approach of MOORA method.

2.1.7 Managerial Implications

Performance measurement provides the feedback or information on activities with respect to meeting customer expectations and strategic objectives. It reflects the need for improvement in areas with unsatisfactory performance. Thus, efficiency and quality can be enhanced (Chan, 2003). The choice of appropriate supply chain performance indicators is rather complicated due to the presence of multiple inputs and multiple outputs in the system (Aramyan et al., 2007). In relation to supply chain performance management, it is often experienced that most of the evaluation criterions are subjective in nature. Subjective evaluation information cannot be analyzed mathematically unless and until they are converted into grey numbers. Grey theory start with and build on a set of user-supplied human language rules. The grey system converts these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world.

[Source:*http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol2/jp6/article2.html*]

Grey numbers theory has the capability of dealing with subjective information which are often vague, inconsistent due to decision-makers' individual perception-discretion. Hence, it is indeed required to establish an efficient performance appraisement module to facilitate in evaluation, selection and benchmarking of supply chain performance extent. Here, the grey MULTIMOORA method is suitable for dealing with uncertain information (e.g., linguistic variables assessed by decision makers). Industries may adopt this appraisement module to compare supply chain performance of different industries running under similar supply chain design and to select the best performing one amongst feasible candidate alternatives.

2.1.8 Concluding Remarks

Performance measurement is critical to the success of almost any organization because it creates understanding, molds behavior and improves competitiveness. Supply chain performance measurement is internally and business focused, and it creates the images of the organization in the global market place, and helps to grip the consumer toward the precious success of organization. This work began with an emphasis on the need for an effective and efficient supply chain performance measurement. It went further to highlight the benefits accruable from the exploration of a grey interval-valued grey numbers (GIVGN) in supply chain performance measurement and provided multiple-criteria hierarchical appraisement modeling for selection of best performing choice (Industry) from available alternatives. This research explored an interval-valued grey set theory combined with MOORA method to facilitate solution of multiple indices appraisement plate form in decision-making environment. The theory of dominance (Brauers and Zavadskas, 2011) could further be applied in the proposed evaluation model which summarized the ranking orders provided by different parts of MOORA, namely the Ratio System and the Reference Point, finally, the result revealed the most suitable alternative in perspective of supply chain performance. The main contributions of the aforesaid research have been highlighted below.

1. Multiple-indices hierarchical appraisement modeling for measurement of supply chain performance.
2. Exploration of grey interval-valued grey numbers (GIVGN) combined with MOORA (Multi-Objective Optimization by Ratio Analysis) in order to evaluate best alternative from among available alternatives tackle subjective evaluation information)
3. Managing the entire supply chain and grip the consumer beyond the success of organization.

Table 2.1: Supply chain performance appraisement modeling (Chan and Qi, 2003)

Goal, C	1st level indices, C_i	2nd level indices, C_{ij}	3rd level indices, C_{ijk}	4th level indices, C_{ijkl}
Supply Chain Performance, C	Supplying, C_1	P & C Design, C_{11}	P & C Design, C_{111}	P & C Design, C_{1111}
		P & C Fabrication, C_{12}	P & C Fabrication, C_{121}	P & C Fabrication, C_{1211}
		Delivery, C_{13}	Delivery Cost, C_{131}	Delivery Cost, C_{1311}
			Delivery Reliability, C_{132}	Timeliness, C_{1321}
				Error-Free, C_{1322}
			Delivery Flexibility, C_{133}	Frequency, C_{1331}
				Amount, C_{1332}
	Inbound Logistics, C_2	Supply Base Management, C_{21}	Supply Base Management, C_{211}	Supply Base Management, C_{2111}
		Transportation, C_{22}	Transport Cost, C_{221}	Transport Cost, C_{2211}
			Transport Productivity, C_{222}	Transport Productivity, C_{2221}
			Transport Flexibility, C_{223}	Transport Flexibility, C_{2231}
			Facility Utilization, C_{224}	Facility Utilization, C_{2241}
		Receiving and Inspection, C_{23}	Receiving and Inspection, C_{231}	Receiving and Inspection, C_{2311}
		Handling and Storing, C_{24}	Handling and Storing, C_{241}	Handling and Storing, C_{2411}
	Core Manufacturing, C_3	Internal Manufacture Operations, C_{31}	Product Quality, C_{311}	Product Quality, C_{3111}
			Operation Costs, C_{312}	Operation Costs, C_{3121}
			Efficiency, C_{313}	Efficiency, C_{3131}
			Flexibility, C_{314}	Flexibility, C_{3141}
			Productivity, C_{315}	Productivity, C_{3151}
		Research and Development, C_{32}	Research and Development, C_{321}	Research and Development, C_{3211}
		Technology and Engineering, C_{33}	Technology and Engineering, C_{331}	Technology and Engineering, C_{3311}
		Maintenance and Storing, C_{34}	Maintenance and Storing, C_{341}	Maintenance and Storing, C_{3411}
	Outbound Logistics, C_4	Transportation, C_{41}	Transportation, C_{411}	Transportation, C_{4111}
		Warehousing, C_{42}	Warehouse Costs, C_{421}	Warehouse Costs, C_{4211}
			Inventory Flow Rate, C_{422}	Inventory Flow Rate, C_{4221}
			Inventory Accuracy, C_{423}	Inventory Accuracy, C_{4231}

			Stock Capacity, C_{424}	Stock Capacity, C_{4241}
			Facility Utilization, C_{425}	Facility Utilization, C_{4251}
		Packing and Shipping, C_{43}	Packing and Shipping, C_{431}	Packing and Shipping, C_{4311}
	Marketing and Sales, C_5	Customer Order Processing and Delivery, C_{51}	Response Time, C_{511}	Response Time, C_{5111}
			Order Fill Rate, C_{512}	Order Fill Rate, C_{5121}
			Order Flexibility, C_{513}	Frequency, C_{5131}
				Amount, C_{5132}
			Delivery Reliability, C_{514}	Timeliness, C_{5141}
				Error-Free, C_{5142}
		Advertising and Customer Services, C_{52}	Advertising and Customer Services, C_{521}	Advertising and Customer Services, C_{5211}

Table 2.2: The scale of attribute evaluation $\otimes G$

Linguistic scale for assigning priority weight	Linguistic scale for assigning attribute rating	Corresponding grey representation $\otimes w$
Very low (VL)	Very Poor (VP)	[0, 1]
low (L)	Poor (P)	[1, 3]
Medium low (ML)	Medium Poor (MP)	[3, 4]
Medium (M)	Fair (F)	[4, 5]
Medium high (MH)	Medium Good (MG)	[5, 6]
High (H)	Good (G)	[6, 9]
Very High (VH)	Very Good (VG)	[9, 10]

Table 2.3: Priority weight (in linguistic scale) of 4^{th} level indices assigned by DMs

4^{th} level indices	Priority weight (in linguistic scale) of 4^{th} level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	M	M	M	VH	VH
C_{1211}	M	M	M	VH	VH
C_{1311}	M	M	M	VH	VH
C_{1321}	M	M	M	VH	VH
C_{1322}	M	M	M	H	H
C_{1331}	M	M	M	H	H
C_{1332}	M	M	M	H	H
C_{2111}	MH	M	M	H	MH
C_{2211}	H	H	MH	ML	H
C_{2221}	VH	H	MH	ML	VH
C_{2231}	H	H	MH	ML	VH
C_{2241}	H	H	MH	MH	VH
C_{2311}	H	MH	VH	H	VH
C_{2411}	H	MH	VH	VH	VH
C_{3111}	M	MH	VH	MH	VH
C_{3121}	M	H	ML	H	VH
C_{3131}	ML	H	ML	VH	VH
C_{3141}	M	M	MH	VH	MH
C_{3151}	M	M	MH	VH	H
C_{3211}	M	M	ML	VH	VH
C_{3311}	H	M	MH	VH	VH
C_{3411}	H	M	H	H	VH
C_{4111}	MH	M	VH	H	VH
C_{4211}	H	H	ML	H	VH
C_{4221}	VH	H	M	H	H
C_{4231}	M	H	M	ML	H
C_{4241}	M	H	M	ML	H

C_{4251}	M	H	M	VL	H
C_{4311}	M	H	M	L	H
C_{5111}	MH	H	M	ML	H
C_{5121}	H	H	M	ML	VH
C_{5131}	VH	M	M	MH	VH
C_{5132}	M	M	ML	MH	VH
C_{5141}	M	M	ML	MH	VH
C_{5142}	M	M	ML	ML	VH
C_{5211}	M	M	ML	ML	VH

Table 2.4: Priority weight (in linguistic scale) of 3rd level indices assigned by DMs

3rd level indices	Priority weight (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{111}	VH	M	VH	M	VH
C_{121}	VH	M	VH	M	VH
C_{131}	VH	M	VH	M	MH
C_{132}	VH	M	VH	H	H
C_{133}	VH	H	H	H	VH
C_{211}	VH	H	H	H	VH
C_{221}	MH	H	H	H	VH
C_{222}	H	H	H	H	VH
C_{223}	VH	MH	ML	H	VH
C_{224}	VH	MH	ML	H	H
C_{231}	VH	MH	ML	H	H
C_{241}	VH	H	MH	M	H
C_{311}	VH	H	H	M	H
C_{312}	H	M	VH	M	M
C_{313}	H	M	MH	M	M
C_{314}	H	M	H	M	M
C_{315}	H	M	VH	VH	M
C_{321}	H	M	VH	VH	M
C_{331}	H	M	VH	VH	H

C_{341}	VH	H	VH	VH	H
C_{411}	VH	H	VH	VH	H
C_{421}	VH	H	H	H	H
C_{422}	VH	H	H	H	H
C_{423}	VH	H	H	H	H
C_{424}	VH	H	H	H	H
C_{425}	M	H	ML	ML	M
C_{431}	M	H	ML	ML	M
C_{511}	M	M	ML	H	M
C_{512}	M	M	MH	VH	M
C_{513}	H	M	H	VH	H
C_{514}	H	M	VH	VH	H
C_{521}	H	M	MH	M	ML

Table 2.5: Priority weight (in linguistic scale) of 2nd level indices assigned by DMs

2nd level indices	Priority weight (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{11}	M	ML	MH	M	MH
C_{12}	M	M	H	VH	H
C_{13}	M	MH	VH	M	VH
C_{21}	M	H	M	VL	M
C_{22}	M	VH	VL	M	VL
C_{23}	VL	M	M	MH	M
C_{24}	H	VL	MH	H	MH
C_{31}	H	H	H	VH	H
C_{32}	H	H	VH	VH	VH
C_{33}	MH	M	VH	M	M
C_{34}	MH	M	M	VL	VL
C_{41}	MH	M	VL	M	H
C_{42}	H	VL	M	M	ML
C_{43}	L	H	M	M	ML
C_{51}	L	ML	VL	VL	ML
C_{52}	VL	ML	H	H	VL

Table 2.6: Appropriateness rating (in linguistic scale) of 4^{th} level indices assigned by DMs (Alternative A_1)

4^{th} level indices	Appropriateness rating (in linguistic scale) of 4^{th} level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	VG	G	G	G	VG
C_{1211}	VG	VG	VG	VG	MP
C_{1311}	MG	F	F	MP	MP
C_{1321}	G	F	F	MP	VG
C_{1322}	VG	F	F	MP	F
C_{1331}	MG	F	P	MP	F
C_{1332}	MG	MP	VG	VG	F
C_{2111}	MG	MP	F	MG	G
C_{2211}	F	MP	F	MG	G
C_{2221}	F	G	MG	MG	G
C_{2231}	G	MG	MG	G	G
C_{2241}	MG	MP	MG	G	G
C_{2311}	MG	MP	F	G	G
C_{2411}	MG	F	F	G	MG
C_{3111}	VG	F	VG	MG	MG
C_{3121}	F	VG	F	MG	MG
C_{3131}	MG	MP	F	G	F
C_{3141}	MG	MP	VG	G	MG
C_{3151}	MG	MP	F	G	MG
C_{3211}	VG	MP	F	G	MG
C_{3311}	F	VG	F	G	MG
C_{3411}	F	F	G	VG	MG
C_{4111}	MG	F	P	VG	VG
C_{4211}	F	F	VP	MG	G
C_{4221}	F	VG	VP	MG	G
C_{4231}	G	F	G	MG	G
C_{4241}	MG	VG	G	MG	VG
C_{4251}	MG	F	G	VG	MG
C_{4311}	MG	MP	G	VG	MG
C_{5111}	MP	MP	G	VG	MG

C_{5121}	MP	MP	P	G	MG
C_{5131}	MG	VG	P	G	VG
C_{5132}	G	F	MP	G	G
C_{5141}	MG	F	MP	G	G
C_{5142}	MG	F	MP	G	G
C_{5211}	G	F	MP	G	G

Table 2.7: Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs (Alternative A_2)

4th level indices	Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	VG	G	G	VG	G
C_{1211}	MP	VG	G	VG	VG
C_{1311}	MP	F	G	MG	F
C_{1321}	VG	F	G	G	F
C_{1322}	F	F	G	VG	F
C_{1331}	F	P	G	MG	P
C_{1332}	F	VG	MG	MG	VG
C_{2111}	G	F	MG	MG	F
C_{2211}	G	F	MG	F	F
C_{2221}	G	MG	F	F	MG
C_{2231}	G	MG	MG	G	MG
C_{2241}	G	MG	MG	MG	MG
C_{2311}	G	F	MG	MG	VG
C_{2411}	MG	F	MG	MG	F
C_{3111}	VP	VG	MG	VG	MG
C_{3121}	VP	F	VG	F	MG
C_{3131}	VP	F	G	MG	MG
C_{3141}	MG	VG	G	MG	VG
C_{3151}	MG	F	G	MG	VP
C_{3211}	MG	F	VG	VP	VP

C_{3311}	MG	F	MG	VP	VP
C_{3411}	MG	G	MG	VP	VP
C_{4111}	VG	VP	MG	VP	VP
C_{4211}	G	VP	MG	F	VG
C_{4221}	G	VP	VG	F	G
C_{4231}	G	G	G	G	G
C_{4241}	VG	G	G	MG	G
C_{4251}	MG	G	G	VG	G
C_{4311}	MG	G	G	G	MG
C_{5111}	MG	G	MG	G	F
C_{5121}	MG	P	F	G	F
C_{5131}	VG	P	F	G	MG
C_{5132}	G	MP	VG	MG	VG
C_{5141}	G	MP	F	MG	G
C_{5142}	G	MP	F	F	G
C_{5211}	G	MP	VG	F	G

Table 2.8: Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs Alternative A_3)

4th level indices	Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	VG	G	VG	F	MP
C_{1211}	VG	G	F	G	VG
C_{1311}	VG	MG	VG	G	F
C_{1321}	F	MG	F	G	F
C_{1322}	VG	MG	MP	G	F
C_{1331}	F	F	MP	G	G
C_{1332}	MP	MG	MP	G	G
C_{2111}	MP	VG	VG	MG	G
C_{2211}	MP	VG	F	MG	G
C_{2221}	VG	F	F	MG	G
C_{2231}	F	VG	F	F	G

C_{2241}	F	G	F	MG	MG
C_{2311}	F	MG	F	VG	MG
C_{2411}	MG	MG	F	VG	MG
C_{3111}	MG	MG	G	F	F
C_{3121}	MG	F	MG	VG	MG
C_{3131}	VG	MG	MG	F	MG
C_{3141}	G	MG	G	MP	MG
C_{3151}	G	F	VG	MP	MG
C_{3211}	G	MG	G	MP	MG
C_{3311}	MG	MG	MG	VG	VG
C_{3411}	MG	MG	MG	F	G
C_{4111}	VG	MG	MG	F	G
C_{4211}	MG	MG	F	MG	G
C_{4221}	MG	VG	MG	MG	VG
C_{4231}	F	G	MG	MG	MG
C_{4241}	MG	MG	MG	VG	MG
C_{4251}	MG	VG	MG	G	MG
C_{4311}	VG	MG	MG	G	MG
C_{5111}	VG	MG	VG	G	VG
C_{5121}	MG	F	G	MG	MG
C_{5131}	VG	MG	G	MG	VG
C_{5132}	G	VG	G	VG	G
C_{5141}	G	MG	VG	MG	G
C_{5142}	G	MG	MG	MG	G
C_{5211}	VG	F	MG	F	VG

Table 2.9: Rating and weight (in linguistic scale) of 4^{th} level metrics assigned by DMs for A_1, A_2 and A_3

4^{th} level metrics	A_1		A_2		A_3	
	Rating	Weight	Rating	Weight	Rating	Weight
C_{1111}	[7.200,9.400]	[6.000,7.000]	[7.200,9.400]	[6.000,7.000]	[6.200,7.600]	[6.000,7.000]
C_{1211}	[7.800,8.800]	[6.000,7.000]	[7.200,8.600]	[6.000,7.000]	[6.800,8.600]	[6.000,7.000]
C_{1311}	[3.800,8.000]	[6.000,7.000]	[4.400,5.800]	[6.000,7.000]	[6.600,8.000]	[6.000,7.000]
C_{1321}	[5.200,6.000]	[6.000,7.000]	[5.800,7.600]	[6.000,7.000]	[4.600,6.000]	[6.000,7.000]

C_{1322}	[4.800,5.800]	[4.800,6.600]	[5.400,6.800]	[4.800,6.600]	[5.400,6.800]	[4.800,6.600]
C_{1331}	[4.000,5.000]	[4.800,6.600]	[3.400,5.200]	[4.800,6.600]	[4.600,6.400]	[4.800,6.600]
$C1_{332}$	[6.000,7.000]	[4.800,6.600]	[6.400,7.400]	[4.800,6.600]	[4.600,6.400]	[4.800,6.600]
C_{2111}	[4.600,6.000]	[4.800,6.200]	[4.800,6.200]	[4.800,6.200]	[6.400,7.800]	[4.800,6.200]
C_{2211}	[4.400,5.800]	[5.200,7.400]	[4.600,6.000]	[5.200,7.400]	[5.400,6.800]	[5.200,7.400]
C_{2221}	[5.200,7.000]	[6.400,7.800]	[4.800,6.200]	[6.400,7.800]	[5.600,7.000]	[6.400,7.800]
C_{2231}	[5.600,7.800]	[5.800,7.600]	[5.400,7.200]	[5.800,7.600]	[5.400,6.800]	[5.800,7.600]
C_{2241}	[5.000,6.800]	[6.200,8.000]	[5.200,6.600]	[6.200,8.000]	[4.800,6.200]	[6.200,8.000]
C_{2311}	[4.800,6.600]	[7.000,8.800]	[5.800,7.200]	[7.000,8.800]	[5.400,6.400]	[7.000,8.800]
C_{2411}	[4.800,6.200]	[7.600,9.000]	[4.600,5.600]	[7.600,9.000]	[5.600,6.600]	[7.600,9.000]
C_{3111}	[6.400,7.400]	[6.400,7.400]	[5.600,6.600]	[6.400,7.400]	[4.800,6.200]	[6.400,7.400]
C_{3121}	[5.400,6.400]	[5.600,7.400]	[4.400,5.400]	[5.600,7.400]	[5.600,6.600]	[5.600,7.400]
C_{3131}	[4.400,5.800]	[6.000,7.400]	[4.000,5.400]	[6.000,7.400]	[5.600,6.600]	[6.000,7.400]
C_{3141}	[5.600,7.000]	[5.400,6.400]	[6.800,8.200]	[5.400,6.400]	[5.000,6.800]	[5.400,6.400]
C_{3151}	[4.600,6.000]	[5.600,7.000]	[4.000,5.400]	[5.600,7.000]	[5.400,6.800]	[5.600,7.000]
C_{3211}	[5.400,6.800]	[5.800,6.800]	[3.600,4.600]	[5.800,6.800]	[5.000,6.800]	[5.800,6.800]
C_{3311}	[5.600,7.000]	[6.600,8.000]	[2.800,3.800]	[6.600,8.000]	[6.600,7.600]	[6.600,8.000]
C_{3411}	[5.600,7.000]	[6.200,8.400]	[3.200,4.600]	[6.200,8.400]	[5.000,6.400]	[6.200,8.400]
C_{4111}	[5.600,6.800]	[6.600,8.000]	[2.800,3.800]	[6.600,8.000]	[5.800,7.200]	[6.600,8.000]
C_{4211}	[3.800,5.200]	[6.000,8.200	[4.800,6.200]	[6.000,8.200	[5.000,6.400]	[6.000,8.200
C_{4221}	[4.800,6.200]	[6.200,8.400]	[5.0006.800]	[6.200,8.400]	[6.600,7.600]	[6.200,8.400]
C_{4231}	[5.400,7.600]	[4.600,6.400]	[6.000,9.000]	[4.600,6.400]	[5.000,6.400]	[4.600,6.400]
C_{4241}	[6.800,8.200]	[4.600,6.400	[6.400,8.600]	[4.600,6.400	[5.800,6.800]	[4.600,6.400]
C_{4251}	[5.800,7.200]	[4.000,5.800]	[6.400,8.600]	[4.000,5.800]	[6.000,7.400]	[4.000,5.800]
C_{4311}	[5.600,7.000]	[4.200,6.200]	[5.600,7.800]	[4.200,6.200]	[6.000,7.400]	[4.200,6.200]
C_{5111}	[5.600,7.000]	[4.800,6.600]	[5.200,7.000]	[4.800,6.600]	[7.600,9.000]	[4.800,6.600]
C_{5121}	[4.000,5.600]	[5.600,7.400]	[4.000,5.600]	[5.600,7.400]	[5.000,6.400]	[5.600,7.400]
C_{5131}	[6.000,7.600]	[6.200,7.200]	[5.000,6.600]	[6.200,7.200]	[6.800,8.200]	[6.200,7.200]
C_{5132}	[5.000,7.200]	[5.000,6.000]	[6.400,7.800]	[5.000,6.000]	[7.200,9.400]	[5.000,6.000]
C_{5141}	[4.800,6.600]	[5.000,6.000]	[4.800,6.600]	[5.000,6.000]	[6.200,8.000]	[5.000,6.000]
C_{5142}	[4.800,6.600]	[4.600,5.600]	[4.600,6.400]	[4.600,5.600]	[5.400,7.200]	[4.600,5.600]
C_{5211}	[5.000,7.200]	[4.600,5.600]	[5.600,7.400]	[4.600,5.600]	[6.200,7.200]	[4.600,5.600]

Table 2.10: Rating and weight (in linguistic scale) of 3rd level metrics assigned by DMs for A_1, A_2 and A_3

3rd level metrics	A_1		A_2		A_3	
	Rating	Weight	Rating	Weight	Rating	Weight
C_{111}	[6.171,10.96]	[7.000,8.000]	[6.171,10.96]	[7.000,8.000]	[5.314,8.867]	[7.000,8.000]
C_{121}	[6.686,10.26]	[7.000,8.000]	[6.171,10.03]	[7.000,8.000]	[5.829,10.03]	[7.000,8.000]
C_{131}	[3.257,5.600]	[6.200,7.200]	[3.771,6.767]	[6.200,7.200]	[5.657,9.333]	[6.200,7.200]
C_{132}	[3.988,7.822]	[6.800,8.600]	[4.465,9.081]	[6.800,8.600]	[3.935,8.044]	[6.800,8.600]
C_{133}	[3.636,8.250]	[7.200,9.400]	[3.564,8.663]	[7.200,9.400]	[3.345,8.800]	[7.200,9.400]
C_{211}	[3.561,7.750]	[7.200,9.400]	[3.716,8.008]	[7.200,9.400]	[4.955,10.07]	[7.200,9.400]
C_{221}	[3.092,8.254]	[6.400,8.600]	[3.232,8.538]	[6.400,8.600]	[3.795,9.677]	[6.400,8.600]
C_{222}	[4.267,8.531]	[6.600,9.200]	[3.938,7.556]	[6.600,9.200]	[4.595,8.531]	[6.600,9.200]
C_{223}	[4.274,10.22]	[6.400,7.800]	[4.121,9.434]	[6.400,7.800]	[4.121,8.910]	[6.400,7.800]
C_{224}	[3.875,8.774]	[5.800,7.600]	[4.030,8.516]	[5.800,7.600]	[3.720,8.000]	[5.800,7.600]
C_{231}	[3.818,8.297]	[5.800,7.600]	[4.614,9.051]	[5.800,7.600]	[4.295,8.046]	[5.800,7.600]
C_{241}	[4.053,7.342]	[6.000,7.800]	[3.884,6.632]	[6.0007.800]	[4.729,7.816]	[6.000,7.800]
C_{311}	[5.535,8.556]	[6.200,8.400]	[4.843,7.631]	[6.200,8.400]	[4.151,7.169]	[6.200,8.400]
C_{312}	[4.086,8.457]	[5.400,6.800]	[3.330,7.136]	[5.400,6.800]	[4.238,8.721]	[5.400,6.800]
C_{313}	[3.568,7.153]	[4.600,6.000]	[3.243,6.660]	[4.600,6.000]	[4.541,8.140]	[4.600,6.000]
C_{314}	[4.725,8.296]	[4.800,6.600]	[5.738,9.719]	[4.800,6.600]	[4.219,8.059]	[4.800,6.600]
C_{315}	[3.680,7.500]	[6.400,7.800]	[3.200,6.750]	[6.400,7.800]	[4.320,8.500]	[6.400,7.800]
C_{321}	[4.606,7.972]	[6.400,7.800]	[3.071,5.393]	[6.400,7.800]	[4.265,7.972]	[6.400,7.800]
C_{331}	[4.620,8.485]	[6.800,8.600]	[2.310,4.606]	[6.800,8.600]	[5.445,9.212]	[6.800,8.600]
C_{341}	[4.133,9.484]	[7.800,9.600]	[2.362,6.232]	[7.800,9.600]	[3.690,8.671]	[7.800,9.600]
C_{411}	[4.620,8.242]	[7.800,9.600]	[2.310,4.606]	[7.800,9.600]	[4.785,8.727]	[7.800,9.600]
C_{421}	[2.780,7.107]	[6.600,9.200]	[3.512,8.473]	[6.600,9.200]	[3.659,8.747]	[6.600,9.200]
C_{422}	[3.543,8.400]	[6.600,9.200]	[3.690,9.213]	[6.600,9.200]	[4.871,10.29]	[6.600,9.200]
C_{423}	[3.881,10.57]	[6.600,9.200]	[4.313,12.52]	[6.600,9.200]	[3.594,8.904]	[6.600,9.200]
C_{424}	[4.888,11.40]	[6.600,9.200]	[4.600,11.96]	[6.600,9.200]	[4.169,9.461]	[6.600,9.200]
C_{425}	[4.000,10.44]	[4.000,5.400]	[4.414,12.47]	[4.000,5.400]	[4.138,10.73]	[4.000,5.400]
C_{431}	[3.794,10.33]	[4.000,5.400]	[3.794,11.51]	[4.000,5.400]	[4.065,10.92]	[4.000,5.400]
C_{511}	[4.073,9.625]	[4.200,5.600]	[3.782,9.625]	[4.200,5.600]	[5.527,12.37]	[4.200,5.600]
C_{512}	[3.027,7.400]	[5.200,6.200]	[3.027,7.400]	[5.200,6.200]	[3.784,8.457]	[5.200,6.200]
C_{513}	[4.712,8.743]	[6.200,8.400]	[4.773,8.421]	[6.200,8.400]	[5.921,10.30]	[6.200,8.400]
C_{514}	[3.972,7.975]	[6.800,8.600]	[3.893,7.858]	[6.800,8.600]	[4.814,9.200]	[6.800,8.600]
C_{521}	[4.107,8.765]	[4.400,5.800]	[4.600,9.009]	[4.400,5.800]	[5.093,8.765]	[4.400,5.800]

Table 2.11: Rating and weight (in linguistic scale) of 2nd level metrics assigned by DMs for A_1, $A_2$and A_3

2rd level metrics	A_1		A_2		A_3	
	Rating	Weight	Rating	Weight	Rating	Weight
C_{11}	[5.400,12.53]	[4.20,5.20]	[5.400,12.53]	[4.20,5.20]	[4.650,10.13]	[4.20,5.20]
C_{12}	[5.850,11.73]	[5.80,7.60]	[5.400,11.46]	[5.80,7.60]	[5.100,11.46]	[5.80,7.60]
C_{13}	[2.917,9.165]	[6.20,7.20]	[3.151,10.30]	[6.20,7.20]	[3.410,10.84]	[6.20,7.20]
C_{21}	[2.728,10.11]	[3.60,5.00]	[2.846,10.45]	[3.60,5.00]	[3.795,13.15]	[3.60,5.00]
C_{22}	[2.945,11.74]	[3.40,4.40]	[2.905,11.16]	[3.40,4.40]	[3.089,11.58]	[3.40,4.40]
C_{23}	[2.914,10.87]	[3.40,4.40]	[3.521,11.86]	[3.40,4.40]	[3.278,10.54]	[3.40,4.40]
C_{24}	[3.118,9.545]	[4.40,6.20]	[2.988,8.621]	[4.40,6.20]	[3.638,10.16]	[4.40,6.20]
C_{31}	[3.343,10.42]	[6.60,9.20]	[3.117,9.831]	[6.60,9.20]	[3.298,10.50]	[6.60,9.20]
C_{32}	[3.779,9.716]	[7.80,9.60]	[2.519,6.573]	[7.80,9.60]	[3.499,9.716]	[7.80,9.60]
C_{33}	[3.653,10.73]	[5.20,6.20]	[1.827,5.825]	[5.20,6.20]	[4.305,11.65]	[5.20,6.20]
C_{34}	[3.358,11.67]	[2.60,3.60]	[1.919,7.670]	[2.60,3.60]	[2.999,10.67]	[2.60,3.60]
C_{41}	[3.754,10.14]	[3.80,5.20]	[1.877,5.669]	[3.80,5.20]	[3.888,10.74]	[3.80,5.20]
C_{42}	[2.740,13.20]	[3.40,4.80]	[2.939,14.97]	[3.40,4.80]	[2.940,13.22]	[3.40,4.80]
C_{43}	[2.810,13.95]	[3.60,5.20]	[2.810,15.54]	[3.60,5.20]	[3.011,14.74]	[3.60,5.20]
C_{51}	[3.093,10.79]	[1.40,2.60]	[3.045,10.63]	[1.40,2.60]	[3.901,12.83]	[1.40,2.60]
C_{52}	[3.116,11.55]	[3.00,4.80]	[3.490,11.87]	[3.00,4.80]	[3.864,11.55]	[3.00,4.80]

Table 2.12: Initial decision-making matrix with values expressed using interval grey numbers

Objectives										
	C_1		C_2		C_3		C_4		C_5	
Significance	0.20		0.19		0.17		0.21		0.23	
Optimization	Max		Max		Max		Max		Max	
Alternatives	$\underline{x}_{1j}$	$\overline{x}_{1j}$	$\underline{x}_{2j}$	$\overline{x}_{2j}$	$\underline{x}_{3j}$	$\overline{x}_{3j}$	$\underline{x}_{4j}$	$\overline{x}_{4j}$	$\underline{x}_{5j}$	$\overline{x}_{5j}$
A_1	3.735	13.601	2.173	14.140	2.772	13.410	2.217	17.468	1.848	18.983
A_2	3.677	13.984	2.262	13.988	1.913	9.787	1.792	16.871	1.991	19.236
A_3	3.512	13.453	2.566	15.279	2.771	13.540	2.343	18.151	2.304	20.187

Table 2.13: Normalized decision-making matrix

Objectives										
	C1		C2		C3		C4		C5	
Significance	0.20		0.19		0.17		0.21		0.23	
Optimization	Max		Max		Max		Max		Max	
Alternatives	$\underline{x}^*_{1j}$	$\overline{x}^*_{1j}$	$\underline{x}^*_{2j}$	$\overline{x}^*_{2j}$	$\underline{x}^*_{3j}$	$\overline{x}^*_{3j}$	$\underline{x}^*_{4j}$	$\overline{x}^*_{4j}$	$\underline{x}^*_{5j}$	$\overline{x}^*_{5j}$
A_1	0.216	0.785	0.121	0.787	0.179	0.868	0.103	0.809	0.077	0.792
A_2	0.212	0.807	0.126	0.779	0.124	0.633	0.083	0.781	0.083	0.802
A_3	0.203	0.776	0.143	0.851	0.179	0.876	0.109	0.841	0.096	0.842

Table 2.14: The ranking results obtained using extended Ratio System Part of the MOORA method

	$i \in \Omega_G^+$		$i \in \Omega_G^-$			
Alternatives	$\sum s_i \underline{x}_{ij}^*$	$\sum s_i \overline{x}_{ij}^*$	$\sum s_i \underline{x}_{ij}^*$	$\sum s_i \overline{x}_{ij}^*$	$\sum_{i \in \Omega_G^+} s_i \underline{x}_{ij}^* - \sum_{i \in \Omega_G^-} s_i \underline{x}_{ij}^*$	$\sum_{i \in \Omega_G^+} s_i \overline{x}_{ij}^* - \sum_{i \in \Omega_G^-} s_i \overline{x}_{ij}^*$
A_1	0.136	0.806	0.0	0.0	0.136	0.806
A_2	0.124	0.766	0.0	0.0	0.124	0.766
A_3	0.143	0.836	0.0	0.0	0.143	0.836

Table 2.15: Ranking results obtained using extended Ratio System Part of MOORA method for $\lambda = 0,\ 0.5,\ 1$

λ	$\lambda = 0$		$\lambda = 0.5$		$\lambda = 1$	
Alternatives	y_j^*	Ranking order	y_j^*	Ranking order	y_j^*	Ranking order
A_1	0.471	**2**	0.136	**2**	0.806	**2**
A_2	0.445	**3**	0.124	**3**	0.766	**3**
A_3	0.490	**1**	0.143	**1**	0.836	**1**

Table 2.16: Reference grey point and distances to reference grey point

Objectives										
	C_1		**C_2**		**C_3**		**C_4**		**C_5**	
Significance	**0.20**		**0.19**		**0.17**		**0.21**		**0.23**	
Optimization	**Max**		**Max**		**Max**		**Max**		**Max**	
$\otimes r$	$\underline{r}_1$	$\overline{r}_1$	$\underline{r}_2$	$\overline{r}_2$	$\underline{r}_3$	$\overline{r}_3$	$\underline{r}_4$	$\overline{r}_4$	$\underline{r}_5$	$\overline{r}_5$
Reference point	**0.216**	**0.807**	**0.143**	**0.851**	**0.179**	**0.876**	**0.109**	**0.841**	**0.096**	**0.842**
Alternatives	$\underline{d}_{1j}$	$\overline{d}_{1j}$	$\underline{d}_{2j}$	$\overline{d}_{2j}$	$\underline{d}_{3j}$	$\overline{d}_{3j}$	$\underline{d}_{4j}$	$\overline{d}_{4j}$	$\underline{d}_{5j}$	$\overline{d}_{5j}$
A_1	0.000	0.022	0.022	0.064	0.000	0.008	0.007	0.032	0.019	0.050
A_2	0.004	0.000	0.017	0.072	0.055	0.243	0.027	0.060	0.013	0.040
A_3	0.013	0.031	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000

Table 2.17: Distances of any alternative to reference point and corresponding ranking order of alternatives, for $\lambda = 0, 0.5, 1$

Alternatives	$\max_i d_{ij}$	$\lambda = 0$ Ranking order	$\max_i d_{ij}$	$\lambda = 0.5$ Ranking order	$\max_i d_{ij}$	$\lambda = 1$ Ranking order
A_1	0.0081	**2**	0.0044	**2**	0.0121	**2**
A_2	0.0506	**3**	0.0094	**3**	0.0412	**3**
A_3	0.0047	**1**	0.0027	**1**	0.0061	**1**

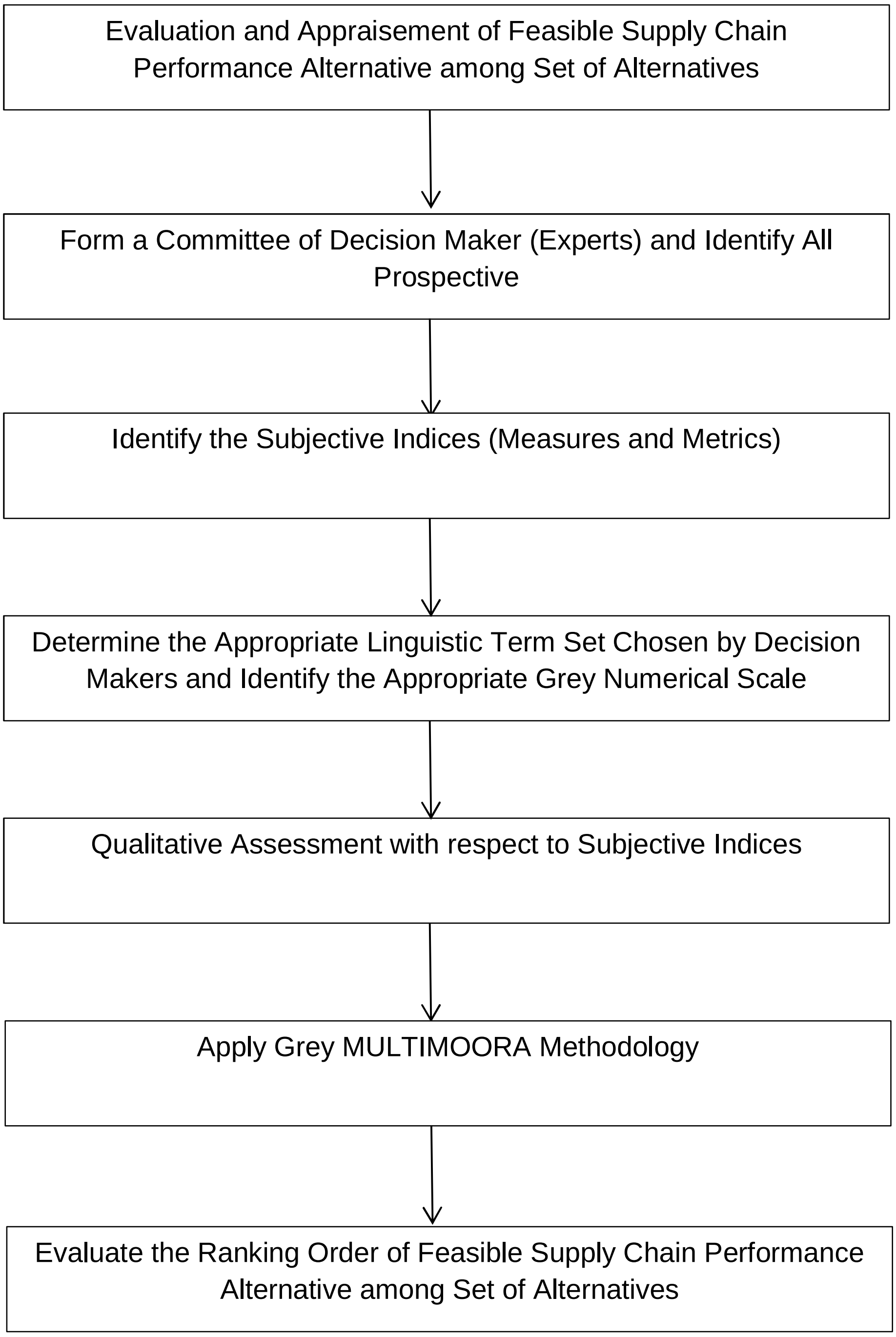

Fig. 2.2: Block diagram of the grey-MOORA method

2.2 Supply Chain Performance Appraisement and Benchmarking: Exploration of Fuzzy-MOORA

2.2.1 Coverage

In today's competitive global marketplace, supply chain management (SCM) has become a key strategic consideration for better realization of organizational goals such as enhancing competitiveness, better customer care and increasing productivity, profitability as well as performance. With the advent of market globalization and outsourcing; many companies are now focusing on improving logistics activities to manage their supply chains efficiently. Most of the companies have now realized that, in order to evolve an efficient and effective supply chain, supply chain needs to be assessed for its performance extent. The performance measurement of the entire supply chain is an important issue because it allows for tracking and tracing of efficacy and efficiency failures and leads to more informed decision-making with regards of the chain design.

Performance measurement is important, as it affects behavior that impacts supply chain performance. As such, performance measurement provides the means by which a company can assess whether its supply chain has improved or degraded. To this end, the present research aims to develop an efficient evaluation framework for selecting the best choice in favor of the performance of alternative industries (corresponding supply chains). In this study, a Fuzzy Multi-Criteria Decision-Making (FMADM) approach combined with MULTI-MOORA (Multi-Objective Optimization by Ratio Analysis) has been explored towards performance appraisement as well as selection of the best industry in accordance with ongoing supply chain performance.

2.2.2 Problem Definition

Supply chain performance assessment, benchmarking, and decision-making are basically complex tasks due to involvement of subjective evaluation information. In any decision-making problem, selecting the best option among alternatives is often a difficult job. This process becomes even more difficult when the evaluation criteria are vague or qualitative, and when the objectives vary in importance and scope. Fuzzy logic/ fuzzy numbers set theory allows for quantitative representation of vague or fuzzy objectives, and therefore, is well-suited for multi-objective decision-making (Hardy, 1995).

Fuzzy Logic is one of the best tools to model imprecise and blurred world. The real world is too complicated for precise descriptions to be obtained; therefore approximations (or fuzziness) must be introduced in order to obtain a reasonable, yet traceable, model (Wang, 1997). Fuzzy logic is the tool for transforming human knowledge and its decision-making ability into a mathematical formula. In other words, it provides with meaningful and powerful representation of measurement uncertainties and also with meaningful representation of vague concepts expressed in natural language (Klir and Yuan, 1995). To this end, present study aims to develop an efficient fuzzy based performance appraisement module towards evaluation, selection and benchmarking of supply chain performance extent. Integrated criteria hierarchy (consisting of 4-level evaluation indices) has been transformed into single layer of evaluation criterions, using fuzzy weighted average method which utilizes performance measures as well as priority weights of individual evaluation indices at 2nd, 3rd and 4th level. Then, fuzzy embedded MULTIMOORA method has been adapted to obtain ranking order of supply chain performance extent of alternative industries.

2.2.3 Fuzzy Preliminaries

Fuzzy sets and fuzzy logic are powerful mathematical tools employed for modeling uncertain systems. A fuzzy set is an extension of a crisp set. A crisp set only allows full membership or non-membership, while fuzzy sets allow partial membership. The theoretical fundaments of fuzzy set theory are overviewed by (Chen, 2000).

Here is a list of general observations about fuzzy logic:

[Source: http://radio.feld.cvut.cz/matlab/toolbox/fuzzy/fuzzyin2.html]

- Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple. What makes fuzzy nice is the ‘naturalness’ of its approach and not its far-reaching complexity.
- Fuzzy logic is flexible. With any given system, it's easy to massage it or layer more functionality on top of it without starting again from scratch.
- Fuzzy logic is tolerant of imprecise data. Everything is imprecise if we look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.
- Fuzzy logic can be built on top of the experience of experts. In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets us rely on the experience of people who already understand the system.

- Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic. Natural language, that which is used by ordinary people on a daily basis, has been shaped by thousands of years of human history to be convenient and efficient. Sentences written in ordinary language represent a triumph of efficient communication. People are generally unaware of this because ordinary language is, of course, something we use every day. Since fuzzy logic is built atop the structures of qualitative description used in everyday language, fuzzy logic is easy to use.

This section presents the concepts and properties of the generalized trapezoidal fuzzy numbers as well as the generalized interval-valued trapezoidal fuzzy numbers. In addition, the arithmetic operations and aggregation of the generalized interval-valued trapezoidal fuzzy numbers are discussed.

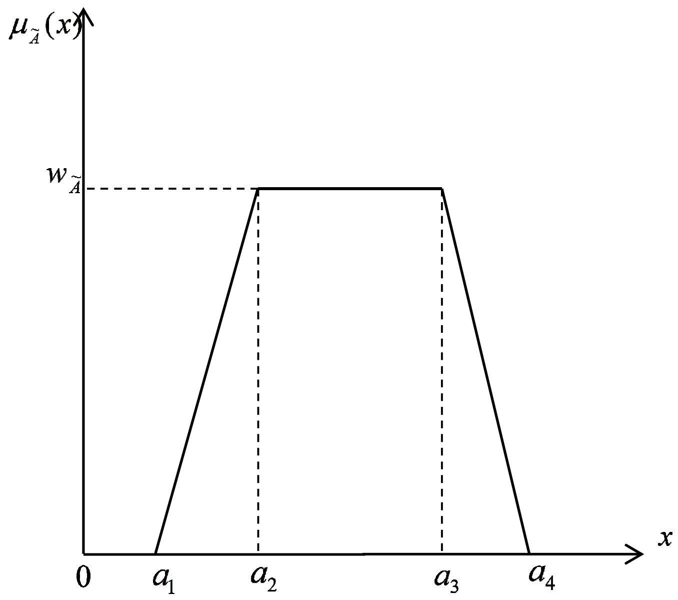

Fig. 2.3: Trapezoidal fuzzy number $\tilde{A}$

2.2.3.1 The Generalized Trapezoidal Fuzzy Numbers

A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$. A trapezoidal fuzzy number can be defined as $\tilde{A}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})$ as shown in Fig. 2.3 and the membership function $\mu_{\tilde{A}}(x):R\rightarrow[0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x)=\begin{cases}\dfrac{x-a_1}{a_2-a_1}\times w_{\tilde{A}}, & x\in(a_1,a_2)\\ w_{\tilde{A}}, & x\in(a_2,a_3)\\ \dfrac{x-a_4}{a_3-a_4}\times w_{\tilde{A}}, & x\in(a_3,a_4)\\ 0, & x\in(-\infty,\ a_1)\cup(a_4,\ \infty)\end{cases} \tag{2.48}$$

Here, $a_1\le a_2\le a_3\le a_4$ and $w_{\tilde{A}}\in(0,1)$

Suppose that $\tilde{a}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})$ and $\tilde{b}=(b_1,b_2,b_3,b_4;w_{\tilde{B}})$ are two trapezoidal fuzzy numbers, then the operational rules of the trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows:

$$\tilde{a}\oplus\tilde{b}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})\oplus(b_1,b_2,b_3,b_4;w_{\tilde{B}})=$$

$$(a_1+b_1,a_2+b_2,a_3+b_3,a_4+b_4;\min(w_{\tilde{A}},w_{\tilde{B}})) \tag{2.49}$$

$$\tilde{a}-\tilde{b}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})-(b_1,b_2,b_3,b_4;w_{\tilde{B}})=$$

$$(a_1-b_4,a_2-b_3,a_3-b_2,a_4-b_1;\min(w_{\tilde{A}},w_{\tilde{B}})) \tag{2.50}$$

$$\tilde{a}\otimes\tilde{b}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})\otimes(b_1,b_2,b_3,b_4;w_{\tilde{B}})=$$

$$\tilde{a}\otimes\tilde{b}=(a_1\times b_1,\ a_2\times b_2,\ a_3\times b_3,\ a_4\times b_4;\min(w_{\tilde{A}},w_{\tilde{B}})) \tag{2.51}$$

$$\tilde{a}/\tilde{b}={(a_1,a_2,a_3,a_4;w_{\tilde{A}})}\Big/{(b_1,b_2,b_3,b_4;w_{\tilde{B}})}$$

$$=(a_1/b_4,a_2/b_3,a_3/b_2,a_4/b_1;\min(w_{\tilde{A}},w_{\tilde{B}})) \tag{2.52}$$

Chen and Chen (2003) introduced the center of gravity (COG) measure for generalized trapezoidal fuzzy numbers. Let there is a generalized trapezoidal fuzzy number $\tilde{A}=\left(a_1,a_2,a_3,a_4;w_{\tilde{A}}\right)$. Then it has its COG point $\left(x_{\tilde{A}},y_{\tilde{A}}\right)$, where,

$$\begin{cases} y_{\tilde{A}}=\begin{cases} w_{\tilde{A}}\left(\dfrac{a_3-a_2}{a_4-a_1}+2\right), & a_1\neq a_4 \\ w_{\tilde{A}}\big/2, & a_1=a_4 \end{cases} \\ x_{\tilde{A}}=\dfrac{y_{\tilde{A}}(a_2+a_3)+(a_1+a_4)+(w_{\tilde{A}}-y_{\tilde{A}})}{2w_{\tilde{A}}} \end{cases} \tag{2.53}$$

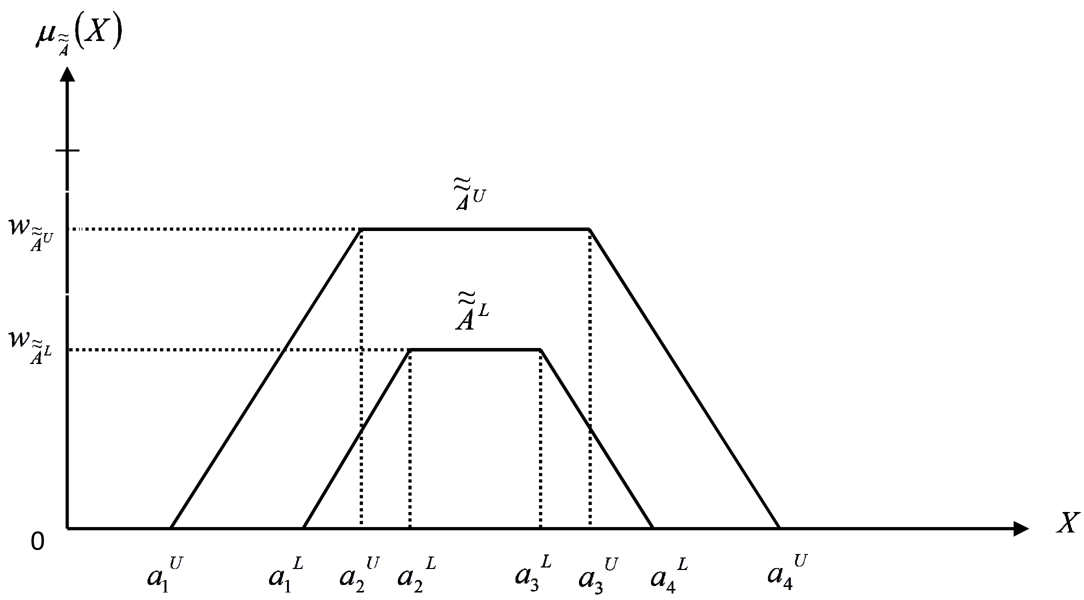

Fig. 2.4: Interval-valued trapezoidal fuzzy numbers

2.2.3.2 The Generalized Interval-Valued Trapezoidal Fuzzy Numbers

The some basic concepts of IVFNs and their arithmetic operations discussed below:

Wei and Chen (2009) defined IVFNs and presented their extended operational rules. The trapezoidal IVFN $\tilde{\tilde{A}}$ has been represented by (Chen and Sanguansat, 2011).

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right],$$

Here $a_1^L \le a_2^L \le a_3^L \le a_4^L$, $a_1^U \le a_2^U \le a_3^U \le a_4^U$, $\tilde{\tilde{A}}^L$ denotes the lower IVFN, $\tilde{\tilde{A}}^U$ denotes the upper IVFN, and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$.

Assume that there are two IVFNs $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$, where;

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \text{ and}$$

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$0 \le w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1,\ \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U,\ 0 \le w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1, \text{ and } \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U.$$

From Fig. 2.4, it can be concluded that interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ consists of the lower values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^U$. The operation rules of interval-valued trapezoidal fuzzy numbers as given by Wei and Chen (2009) have been reproduced below.

Suppose that,

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \text{ and}$$

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

are the two interval-valued trapezoidal fuzzy numbers, where,

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$$
$$0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U} \le 1, \quad \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,$$
$$0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{B}}^L} \le w_{\tilde{\tilde{B}}^U} \le 1, \quad \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U$$

*(i)**The sum of two interval-valued trapezoidal fuzzy numbers** $\tilde{\tilde{A}} \oplus \tilde{\tilde{B}}$ **:***

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \oplus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix} \tag{2.54}$$

*(ii)**The difference of two interval-valued trapezoidal fuzzy numbers** $\tilde{\tilde{A}} - \tilde{\tilde{B}}$ **:***

$$\tilde{\tilde{A}} - \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] - \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(a_1^L - b_4^L, a_2^L - b_3^L, a_3^L - b_2^L, a_4^L - b_1^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(a_1^U - b_4^U, a_2^U - b_3^U, a_3^U - b_2^U, a_4^U - b_1^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix} \tag{2.55}$$

*(iii)**The product of two interval-valued trapezoidal fuzzy numbers** $\tilde{\tilde{A}} \otimes \tilde{\tilde{B}}$ **:***

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \otimes \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix} \tag{2.56}$$

*(iv)**The product between an interval-valued trapezoidal fuzzy number and a constant** $\lambda\tilde{\tilde{A}}$ **:***

$$\lambda\tilde{\tilde{A}} = \lambda \times \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

$$=\left[\left(\lambda a_1^L,\lambda a_2^L,\lambda a_3^L,\lambda a_4^L;w_{\tilde{\tilde{A}}^L}\right),\left(\lambda a_1^U,\lambda a_2^U,\lambda a_3^U,\lambda a_4^U;w_{\tilde{\tilde{A}}^U}\right)\right],\quad \lambda>0. \tag{2.57}$$

*(v)**The division between two interval-valued trapezoidal fuzzy numbers*** $\tilde{\tilde{A}}/\tilde{\tilde{B}}$

$$\tilde{\tilde{A}}/\tilde{\tilde{B}}=\left[\left(a_1^L,a_2^L,a_3^L,a_4^L;w_{\tilde{\tilde{A}}^L}\right),\left(a_1^U,a_2^U,a_3^U,a_4^U;w_{\tilde{\tilde{A}}^U}\right)\right]/\left[\left(b_1^L,b_2^L,b_3^L,b_4^L;w_{\tilde{\tilde{B}}^L}\right),\left(b_1^U,b_2^U,b_3^U,b_4^U;w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$=\begin{bmatrix}\left(\min(U^L),\min(U^L/x^L),\max(U^L/y^L),\max(U^L);\min\left(w_{\tilde{\tilde{A}}^L},w_{\tilde{\tilde{B}}^L}\right)\right),\\ \left(\min(U^U),\min(U^U/x^U),\max(U^U/y^U),\max(U^U);\min\left(w_{\tilde{\tilde{A}}^U},w_{\tilde{\tilde{B}}^U}\right)\right)\end{bmatrix}$$

Here,

$$U^L=\left\{\frac{a_1{}^L}{b_1{}^L},\frac{a_2{}^L}{b_2{}^L},\frac{a_3{}^L}{b_3{}^L},\frac{a_4{}^L}{b_4{}^L}\right\},\ U^L=\left\{\frac{a_1{}^U}{b_1{}^U},\frac{a_2{}^U}{b_2{}^U},\frac{a_3{}^U}{b_3{}^U},\frac{a_4{}^U}{b_4{}^U}\right\}, \tag{2.58}$$

$$x^L=\min(U^L),x^U=\min(U^U),y^L=\max(U^L),y^U\max(U^U)$$

and the operator ''/''denotes exclusion of a certain term from sets U^L and U^U.

(vi) ***Rising to the power of a constant*** λ ***,***

$$\tilde{\tilde{A}}^\lambda=\left[\left(a_1^L,a_2^L,a_3^L,a_4^L;w_{\tilde{\tilde{A}}^L}\right),\left(a_1^U,a_2^U,a_3^U,a_4^U;w_{\tilde{\tilde{A}}^U}\right)\right]^\lambda$$

$$\left[\left((a_1^L)^\lambda,(a_2^L)^\lambda,(a_3^L)^\lambda,(a_4^L)^\lambda,w_{\tilde{\tilde{A}}^L}\right),\left((a_1^U)^\lambda,(a_2^U)^\lambda,(a_3^U)^\lambda,(a_4^U)^\lambda,w_{\tilde{\tilde{A}}^U}\right)\right] \tag{2.59}$$

By considering Eq. 2.53, we can define the COG point for an interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}=\left[\tilde{\tilde{A}}^L,\tilde{\tilde{A}}^U\right]=\left[\left(a_1^L,a_2^L,a_3^L,a_4^L;w_{\tilde{\tilde{A}}^L}\right),\left(a_1^U,a_2^U,a_3^U,a_4^U;w_{\tilde{\tilde{A}}^U}\right)\right]$. Firstly, Eq. 2.53 is employed to obtain the coordinates of the COG points for the lower and upper values of $\tilde{\tilde{A}}$ viz. $\left(x_{\tilde{\tilde{A}}^L},y_{\tilde{\tilde{A}}^L}\right)$and $\left(x_{\tilde{\tilde{A}}^U},y_{\tilde{\tilde{A}}^U}\right)$ for $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{A}}^U$, respectively. Secondly, the COG of $\left(x_{\tilde{\tilde{A}}},y_{\tilde{\tilde{A}}}\right)$ is found as follows:

$$\begin{cases} x_{\tilde{\tilde{A}}} = \left(x_{\tilde{\tilde{A}}^L} + x_{\tilde{\tilde{A}}^U}\right)/2 \\ y_{\tilde{\tilde{A}}} = \left(y_{\tilde{\tilde{A}}^L} + y_{\tilde{\tilde{A}}^U}\right)/2 \end{cases} \tag{2.60}$$

Let there exist an interval-valued fuzzy number

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

One can define the COG point $\left(x_{\tilde{\tilde{B}}}, y_{\tilde{\tilde{B}}}\right)$ in the spirit of Eq. 2.53. The distance $d_{\tilde{\tilde{A}}}$ and $d_{\tilde{\tilde{B}}}$ between the origin point and two generalized interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ $\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$ and $\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$ respectively, are calculated by virtue of the Euclidean distance:

$$d_{\tilde{\tilde{A}}} = \sqrt{x_{\tilde{\tilde{A}}}^2 + y_{\tilde{\tilde{A}}}^2}$$

$$d_{\tilde{\tilde{B}}} = \sqrt{x_{\tilde{\tilde{B}}}^2 + y_{\tilde{\tilde{B}}}^2} \tag{2.61}$$

Accordingly, if $d_{\tilde{\tilde{A}}} > d_{\tilde{\tilde{B}}}$, then $\tilde{\tilde{A}} \succ \tilde{\tilde{B}}$

The COG coordinates can also be employed when estimating the distance between two interval-valued trapezoidal fuzzy number say $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ (Liu, 2011a, b)

$$d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \sqrt{\left\{\left(x_{\tilde{\tilde{A}}^L} - x_{\tilde{\tilde{B}}^L}\right)^2 + \left(y_{\tilde{\tilde{A}}^L} - y_{\tilde{\tilde{B}}^L}\right)^2 + \left(x_{\tilde{\tilde{A}}^U} - x_{\tilde{\tilde{B}}^U}\right)^2 + \left(y_{\tilde{\tilde{A}}^U} - y_{\tilde{\tilde{B}}^U}\right)^2\right\}/4} \tag{2.62}$$

Alternatively, one can employ the following technique (Liu and Jin, 2012):

$$d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{8}\begin{pmatrix} \left|w_{\tilde{\tilde{A}}^L} a_1^L - w_{\tilde{\tilde{B}}^L} b_1^L\right| + \left|w_{\tilde{\tilde{A}}^L} a_2^L - w_{\tilde{\tilde{B}}^L} b_2^L\right| + \left|w_{\tilde{\tilde{A}}^L} a_3^L - w_{\tilde{\tilde{B}}^L} b_3^L\right| \\ + \left|w_{\tilde{\tilde{A}}^L} a_4^L - w_{\tilde{\tilde{B}}^L} b_4^L\right| + \left|w_{\tilde{\tilde{A}}^U} a_1^U - w_{\tilde{\tilde{B}}^U} b_1^U\right| + \left|w_{\tilde{\tilde{A}}^U} a_2^U - w_{\tilde{\tilde{B}}^U} b_2^U\right| + \\ \left|w_{\tilde{\tilde{A}}^U} a_3^U - w_{\tilde{\tilde{B}}^U} b_3^U\right| + \left|w_{\tilde{\tilde{A}}^U} a_4^U - w_{\tilde{\tilde{B}}^U} b_4^U\right| \end{pmatrix} \tag{2.63}$$

2.2.3.3 The Generalized Interval-Valued Trapezoidal Fuzzy Numbers Ordered Weighted Geometric Average Operator

Group multi-criteria decision-making requires certain methods to aggregate the opinions provided by different experts. Yager (1988) therefore proposed an interesting and well-grounded approach, named the ordered weighted average (OWA), which enabled to aggregate the variables in terms of their order in the set. Such an approach enables to avoid the subjectivity arising from group decision-making. Liu and Jin (2012) introduced the generalized interval-valued trapezoidal fuzzy numbers ordered weighted geometric average (GIFNOWGA) operator which enables to tackle fuzzy variables.

Let $\approx{A}_j$ is a set of generalized interval-valued trapezoidal fuzzy numbers,

$\tilde{\tilde{A}}_j = \left[\tilde{\tilde{A}}_j^L, \tilde{\tilde{A}}_j^U\right] = \left[\left(a_{1j}^L, a_{2j}^L, a_{3j}^L, a_{4j}^L; \tilde{\tilde{w}}_{A_j^L}\right), \left(a_{1j}^U, a_{2j}^U, a_{3j}^U, a_{4j}^U; \tilde{\tilde{w}}_{A_j^U}\right)\right]$ with $j = 1,2,...,n$; Ω is the set of all generalized interval-valued trapezoidal fuzzy numbers; and $(\sigma(1), \sigma(2), ..., \sigma(n))$ is a permutation of $(1,2,...,n)$, such that $\tilde{\tilde{A}}_{\sigma(j-1)} \succ \tilde{\tilde{A}}_{\sigma(j)}, \forall j = 2,3,...,n.$ Then we have GITFNOWGA: $\Omega^n \rightarrow \Omega$, which can be employed in the following way:

$$GITFNOWGA_w\left(\tilde{\tilde{A}}_1, \tilde{\tilde{A}}_2, ..., \tilde{\tilde{A}}_n\right) = \prod_{j=1}^{n}\left(\tilde{\tilde{A}}_{\sigma(j)}\right)^{w_j}$$

$$= \prod_{j=1}^{n}\left[\left(a_{1\sigma(j)}^L, a_{2\sigma(j)}^L, a_{3\sigma(j)}^L, a_{4\sigma(j)}^L; w_{\tilde{\tilde{A}}_{\sigma(j)}^L}\right), \left(a_{1\sigma(j)}^U, a_{2\sigma(j)}^U, a_{3\sigma(j)}^U, a_{4\sigma(j)}^U; w_{\tilde{\tilde{A}}_{\sigma(j)}^U}\right)\right]^{w_j} \quad (2.64)$$

Here w_j is a weight attributed to the j_{th} largest variable $(j = 1,2,...,n)$. The vector of weights can be obtained by virtue of the following equation: (Baležentis and Zeng, 2013)

$$w_{i+1} = \frac{C_{n-1}^{i}}{2^{n-1}}, \forall i = 0,1,..., n-1. \quad (2.65)$$

2.2.4 The Crisp MULTIMOORA method

The Multi-Objective Optimization by Ratio Analysis (MOORA) method was introduced by Brauers and Zavadakas (2006). Brauers and Zavadakas (2010) extended the method to make it more robust as MULTIMOORA (MOORA plus the full multiplicative form).

MOORA method begins with matrix X where its elements x_{ij} denote i_{th} alternative of j_{th} objective $(i = 1,2,...,m;\ j = 1,2,...,n)$. MOORA method consists of two parts: the Ratio System and the Reference Point Approach. The MULTIMOORA method includes internal normalization and treats originally **all the objectives equally important**. In principle all stakeholders interested in the issue only could give more importance to an objective. Therefore, they could either multiply the dimensionless number representing the response on an objective with a significance coefficient or they could decide beforehand to split an objective into different sub-objectives.

1. The Ratio System of MOORA

Ratio System defines data normalization by comparing alternative of an objective to all values of the objective:

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{2.66}$$

Here x_{ij}^* denotes i_{th} alternative of j_{th} objective. Usually these numbers belong to the interval [0, 1].

These indicators are added (if desirable value of indicator is maximum) or subtracted (if desirable value is minimum), thus the summarizing index of each alternative is derived in this way:

$$y_i^* = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^*, \tag{2.67}$$

Here $g = 1,...,n$ denotes number of objectives to be maximized. Then every ratio is given the rank: the higher the index, the higher the rank.

In some cases, it is often observed that some attributes are more important than the others. In order to give more importance to an attribute, it could be multiplied with its corresponding weight (significance coefficient) (Brauers and Zavadskas, 2009; Chakraborty, 2011). When these attribute weights are taken into consideration, Eq. 2.67 becomes as follows:

$$y_i^* = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^*, \quad j = 1,2,...,n. \tag{2.68}$$

Here w_j is the weight of j_{th} attribute.

2. The Reference Point of MOORA

Reference point approach is based on the Ratio System. The Maximal Objective Reference Point (vector) is found according to ratios found by employing Eq. 2.69. The j_{th} coordinate of the reference point can be described as ($r_j = \max x_{ij}^*$) in case of maximization. Every coordinate of this vector represents maximum or minimum of certain objective (indicator). Then every element of normalized response matrix is recalculated and final rank is given according to deviation from the reference point and the Min-Max Metric of Tchebycheff:

$$\min_i \left(\max_j \left| r_j - x_{ij}^* \right| \right) \tag{2.69}$$

3. The Full Multiplicative Form and MULTIMOORA

(Brauers and Zavadskas, 2006) proposed MOORA to be updated by the Full Multiplicative Form method embodying maximization as well as minimization of purely multiplicative utility function. Overall utility of the i_{th} alternative can be expressed as dimensionless number:

$$U_i^{'} = \frac{A_i}{B_i} \tag{2.70}$$

Here $A_i = \prod_{j=1}^{g} x_{ij}; i = 1,2,...,m$ denotes the product of objectives of the i_{th} alternative to be maximized with $g = 1,2,...,n$ being the number of objectives to be maximized and where $B_i = \prod_{j=g+1}^{n} x_{ij}; i = 1,2,...,m$ denotes the product of objectives of the i_{th} alternative to be minimized with $n - g$ being the number of objectives (indicators) to be minimized. Thus MULTIMOORA summarizes MOORA (i.e. Ratio System and Reference Point) and the Full Multiplicative Form.

2.2.5 MULTIMOORA Method Based Upon Interval-Valued Trapezoidal Fuzzy Numbers

Let $k = 1,2,..., K$ denotes the k_{th} expert involved in a decision-making process. Suppose that the experts provide ratings for each i_{th} alternative against each j_{th} criterion with $i = 1,2,..., m$ and $j = 1,2,..., n$. The set of criteria can be split into two subsets, namely those of cost criteria, C, and benefit criteria, B. Cost criteria are to be minimized whereas; benefit criteria are to be maximized. Each criterion can be attributed with respective weight ϖ_j, such that $\varpi_j \geq 0$, and $\sum_j \varpi_j = 1$.

Step 1: Each of decision-makers constructs his own decision matrix:

$\left(\tilde{\tilde{A}}^k\right)_{m\times n}$ with elements $\tilde{\tilde{a}}_{ij}^k = \left[\left(a_{ijk1}^L, a_{ijk2}^L, a_{ijk3}^L, a_{ijk4}^L; w_{ijk}^L\right), \left(a_{ijk1}^U, a_{ijk2}^U, a_{ijk3}^U, a_{ijk4}^U; w_{ijk}^U\right)\right]$ being responses of alternatives on criteria.

Step 2: Individual decision matrices are aggregated by employing the GITFNOWGA operator.

$$GITFNOWGA_w\left(\tilde{\tilde{a}}_{ij}^1, \tilde{\tilde{a}}_{ij}^2, ..., \tilde{\tilde{a}}_{ij}^K\right) = \prod_{k=1}^{K}\left(a_{ij}^{\sigma(k)}\right)^{w_k}, \forall i, j, \tag{2.71}$$

Here w_k is the weight of the k_{th} largest response obtained by Eq. 2.65 and

$\tilde{\tilde{a}}_{ij} = \left[\left(a_{ij1}^L, a_{ij2}^L, a_{ij3}^L, a_{ij4}^L; w_{ij}^L\right), \left(a_{ij1}^U, a_{ij2}^U, a_{ij3}^U, a_{ij4}^U; w_{ij}^U\right)\right]$

It must be noted that Eq. 2.61 is employed to compare the values of the generalized interval-valued trapezoidal fuzzy numbers.

Step 3: In case some of criteria involve numeric data, the normalization has to be carried out.

$$\tilde{\tilde{x}}_{ij} = \left[\left(\frac{a_{ij1}^L}{d_j}, \frac{a_{ij2}^L}{d_j}, \frac{a_{ij3}^L}{d_j}, \frac{a_{ij4}^L}{d_j}; w_{ij}^L\right), \left(\frac{a_{ij1}^U}{d_j}, \frac{a_{ij2}^U}{d_j}, \frac{a_{ij3}^U}{d_j}, \frac{a_{ij4}^U}{d_j}; w_{ij}^U\right)\right] \tag{2.72}$$

$$= \left[\left(x_{ij1}^L, x_{ij2}^L, x_{ij3}^L, x_{ij4}^L; w_{ij}^L\right), \left(x_{ij1}^U, x_{ij2}^U, x_{ij3}^U, x_{ij4}^U; w_{ij}^U\right)\right],$$

$j = 1,2,..., n; i = 1,2,..., n.$

Here $d_j = \sqrt{\sum_{i=1}^{m}\sum_{p=1}^{4}\left(a_{ijp}^L\right)^2 + \sum_{i=1}^{m}\sum_{p=1}^{4}\left(a_{ijp}^U\right)^2}$,

$p = \{1,2,3,4\}$ for $\forall j = 1,2,...,n.$

Step 4: The Ratio System

The normalized values are added up for the benefit criteria and subtracted for the cost criteria:

$$RS_i = \sum_{j \in B} \tilde{\tilde{x}}_{ij} - \sum_{j \in C} \tilde{\tilde{x}}_{ij}$$
$$= \left[\left(RS_{i1}^L, RS_{i2}^L, RS_{i3}^L, RS_{i4}^L; w_{RS_i}^L\right), \left(RS_{i1}^U, RS_{i2}^U, RS_{i3}^U, RS_{i4}^U; w_{RS_i}^U\right)\right] \tag{2.73}$$

Here RS_i denotes the overall utility of the i_{th} alternative in terms of the Ratio System. The alternatives are then ranked by measuring their distances from the origin point in the spirit of Eq. 2.61. Specially, alternatives with higher distances receive higher ranks.

Step 5: The Reference Point Approach

For the sake of convenience one can employ the Maximal Utopian Reference Point (MURP), rather than the Maximal Objective Reference Point. In case of the generalized interval-valued trapezoidal fuzzy numbers, MURP is defined as follows:

$$\tilde{\tilde{r}}_j = \begin{cases} (1,1,1,1;1), & \forall j \in B \\ (0,0,0,0;1), & \forall j \in C \end{cases} \tag{2.74}$$

Thereafter, Eq. 2.62 and 2.63 can be utilized to identify the maximal deviation from the MURP for each alternative:

$$\max_j d\left(\tilde{\tilde{r}}_j, \tilde{\tilde{x}}_{ij}\right). \tag{2.75}$$

Then the alternatives are ranked by minimizing the maximal deviances found in Eq. 2.74.

Step 6: The Full Multiplicative Form

The fuzzy utility of the i_{th} alternative is obtained by employing Eq. 2.57 and Eq. 2.58.

$$\tilde{\tilde{U}}_i = \frac{\tilde{\tilde{A}}_i}{\tilde{\tilde{B}}_i} \tag{2.76}$$

Here $\tilde{\tilde{A}}_i = \prod_{j\in B} \tilde{\tilde{x}}_{ij}, i = 1,2,...,m$ denotes the product of objectives of the i_{th} alternative to be maximized with B being the set of objectives to be maximized, and where $\tilde{\tilde{B}}_i = \prod_{j\in C} \tilde{\tilde{x}}_{ij}$ denotes the product of objectives of the i_{th} alternative to be minimized with C being the set of objectives (indicators) need to be minimized. The alternatives are ranked in descending order of $\tilde{\tilde{U}}_i$ by employing Eq. 2.61.

Step 7: The Dominance theory (Brauers and Zavadskas, 2011) is employed to aggregate the three ranks provided by respective parts of MULTIMOORA.

As one can note, the MULTIMOORA involves multiplication and division operations. The use of the most extreme linguistic values of zero therefore should be avoided. Otherwise, alternatives attributed with particularly low values against some criteria should be dropped from the further analysis.

2.2.6 Case Empirical Research

The supply chain performance evaluation index platform (Chan and Qi, 2003) adapted in this paper has already been shown in (Table 2.1) of Section 2.1.7. Assume that there are three alternative industries correspond to similar supply chain architecture. Our objective is to select the best one with respect to its supply chain performance. The 4-level hierarchical model consists of various indices: measures and metrics. Supplying (S), Inbound Logistics (IL), Core Manufacturing (CM), Outbound Logistics (OL), Marketing and Sales (M&S) have been considered as the 1st level indices (called measures) followed by 2nd level indices, then 3rd level indices and finally the 4th level indices which encompass numerous supply chain performance metrics. A MULTIMOORA approach combined with Interval-Valued Fuzzy Numbers Set (IVFNS) has been explored in perceptive to evaluate a supply chain performance alternative. This method has been found fruitful for solving such a group decision-making problem under uncertain environment due to vagueness, inconsistency and incompleteness associated with decision-makers' subjective evaluation information.

Empirical research has been carried out to verify application procedural steps of the proposed approach towards evaluation of supply chain performance alternative under a fuzzy environment. Assume that a committee of five decision-makers (expert group) such as

$DM_1, DM_2, DM_3, DM_4, DM_5$ has been constructed from academicians, manager of production unit, marketing unit, material purchasing unit and his/her team. Also, assume that there were three alternative supply chains such as $A_{1,}$ A_2 and A_3.

In this part of, priority weights against individual performance measures-metrics and corresponding performance extent (appropriateness rating) have been obtained by linguistic information, provided by the expert group; which have been further transformed into IV-trapezoidal fuzzy numbers. Here, these linguistic variables corresponding to weight assignment of various performance measures-metrics (from 1st to 4th level of the evaluation hierarchy; Table 2.18) has been expressed in fuzzy numbers by 1-9 scale as shown in Table 2.18. Similarly, the fuzzy performance ratings of individual evaluation metrics in 4th level have also been expressed in fuzzy numbers by 1-9 scale shown in Table 2.18. The procedural steps and its implementation results have been summarized as follows:

Step 1: Gathering information from the expert group in relation to performance rating and importance weights of different evaluation measures/metrics using linguistic terms

For evaluating importance weights of numerous supply chain measures/metrics (from 1st level to 4th level), as well as appropriateness rating only for 4th level metrics; a committee of fives decision-makers (DMs), $DM_1, DM_2, DM_3, DM_4, DM_5$ has been formed to express their subjective preferences (evaluation score) in linguistic terms shown in (Table 2.18) which have been further transformed into IV-fuzzy number. The linguistic variables for assessing importance weights of various supply chain indices as given by the decision-makers (DMs) have been shown in Tables 2.19-2.22, for 4th level, 3rd level, 2nd, and 1st level indices, respectively. The appropriateness rating (in linguistic terms) against individual 4th level evaluation indices as assigned by the decision-makers have been furnished in Tables 2.23-2.26, for alternative A_1, A_2 and A_3, respectively.

Step 2: Approximation of the linguistic evaluation information by IV trapezoidal fuzzy numbers

Using the concept of generalized trapezoidal Interval-Valued fuzzy numbers in fuzzy set theory, the linguistic variables have been transformed into corresponding appropriate fuzzy numbers shown in (Table 2.18). Next, based on simple fuzzy average rule; the aggregated fuzzy priority weights for (4th level, 3rd level, 2nd level and 1st level indices) have been computed and shown in Tables 2.26-2.29 (for alternative A_1), Tables 2.30-2.33 (for alternative A_2) and Tables 2.34-2.37

(for alternative A_3). To avoid computational complexity, in this computation instead of using the addition arithmetic operator (GITFNO) Eq. 2.71; simple fuzzy average rule has been adapted to compute aggregated weights of various evaluation indices at various levels. Similarly, aggregated performance ratings of various 4th level indices have been computed. Following the backward path (starting from 4th level in the evaluation hierarchy) and exploring fuzzy weighted average rule; performance ratings of different evaluation indices at preceding levels (3rd, 2nd and finally 1st level) have been computed.

Appropriateness rating (also called Fuzzy Performance Index, FPI) for each of the 3rd level evaluation index U_{ijk} (rating of k_{th} index) has been computed as follows:

$$FPI = U_{ijk} = \frac{\sum U_{ijkl} \otimes w_{ijkl}}{\sum w_{ijkl}} \tag{2.77}$$

In this expression (Eq. 2.77) U_{ijkl} is denoted as the aggregated fuzzy appropriateness rating against l_{th} index (at 4th level) which is under k_{th} index in the 3rd level, under j_{th} index in the 2nd level and under i_{th} index in the 1st level. w_{ijkl} is the aggregated fuzzy weight against l_{th} index (at 4th level).

Appropriateness rating for each of the 2nd level evaluation index U_{ij} (rating of j_{th} index) has been computed as follows:

$$FPI = U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ijk}} \tag{2.78}$$

In this expression (Eq. 2.78) U_{ijk} is denoted as the computed fuzzy appropriateness rating (obtained using Eq. 2.77) against k_{th} index (at 3rd level) which is under j_{th} index in the 2nd level and under i_{th} index in the 1st level. w_{ijk} is the aggregated fuzzy weight against k_{th} index (at 3rd level).

Appropriateness rating for each of the 1st level evaluation index U_i (rating of i_{th} index) has been computed as follows:

$$FPI = U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{2.79}$$

In this expression (Eq. 2.79) U_{ij} is denoted as the computed fuzzy appropriateness rating (obtained from Eq. 2.78) against j_{th} index (at 2nd level) which is under i_{th} index in the 1st level. w_{ij} is the aggregated fuzzy weight against j_{th} -index (at 2nd level) which is under i_{th} index at 1st level.

The computation results have been shown in Tables 2.26-2.29 (for alternative A_1), Tables 2.30-2.33 (for alternative A_2) and Tables 2.34-2.37 (for alternative A_3).

Thus, the problem appears to solve a feasible solution from the decision-making matrix, involving a number of feasible alternatives corresponding to a set of evaluation criteria.

$$\begin{array}{c c} & \begin{array}{ccccc} C_1 & C_2 & C_2 & C_4 & C_5 \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ A_3 \end{array} & \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} \end{bmatrix} \end{array}$$

Step 4: Normalization

All of the indices/metric have been assumed beneficial in nature and expressed in terms of generalized interval-valued trapezoidal fuzzy numbers but usually these numbers belong to the interval [0; 1] so, normalization has been carried out by employing Eq. 2.72. The normalized weighted matrix has been shown in Table 2.38.

Step 5: The Ratio System

The Ratio System, the normalized values have been added up for the benefit criteria and (subtracted for the cost criteria) (Eq. 2.73) shown in (Table 2.69). In this computation priority weight of individual evaluation criterions have been considered.

Step 5 Reference Point Approach

We define the Reference Point (assuming all criteria are benefit in nature):

$\tilde{\tilde{r}}_i = (1,1,1,1;1)$

Thus, the ranking order of the alternatives in terms of their distances can be computed from Eqs. (2.61-2.63). A Smaller distances of measures corresponds to higher ranking position (Table 2.40).

Step 6 The Full Multiplicative Form

The Eq. 2.76 has been employed to obtain ranking order for each of alternatives according to the MOORA method with Full Multiplicative Form and the results have been shown in Table 2.41.

Step 7 Final Ranking Order Utilizing Dominance Theory

By using different computational concepts in MOORA method: *Ratio System*, *Reference Point* and *Full Multiplicative Form* to rank the supply chain performance alternatives; the Dominance Theory (Brauers and Zavadskas, 2011) has been finally employed to summarize the three different ranking orders provided by respective parts of fuzzy integrated MULTIMOORA approach. Table 2.42 presents the final ranking order of feasible alternative set. According to the multi-criteria evaluation, the third alternative (A_3) should be best choice as per the judgment of decision makers, whereas the second alternative (A_2) is the second-best choice. At the other end of spectrum, first alternative A_1 is the worst choice.

2.2.7 Managerial Implications

As a new management model, supply chain is an effective way that the enterprise can obtain a competitive advantage and improve economic benefit. Performance evaluation of supply chain plays an increasingly important role as a comprehensive feedback control activity in the business management. So, how to evaluate the performance of supply chain has become the hot research topic in the supply chain enterprise (Hongxia and Zhipeng, 2007). Performance evaluation is very important as a strategic tool and also provides means to achieve the objectives required, fulfilling a firm's mission/strategy statement (Shuka et al., 2011). In relation to supply chain performance management, it is often experienced that most of the evaluation criterions are subjective in nature. Subjective evaluation information cannot be analyzed mathematically unless and until they are converted into fuzzy numbers. Fuzzy logic has the capability of dealing with subjective information which are often vague, inconsistent due to decision-makers' individual perception-discretion. Hence, it is indeed required to establish an efficient performance appraisement module to facilitate evaluation, selection as well as benchmarking of supply chain performance extent. The IVFN based MULTIMOORA approach presented in this study seems fruitful to aid decision-making in fuzzy environment involving ambiguity in linguistic evaluation information. Industries may adopt this appraisement module to compare supply chain performance of different industries running under similar supply chain design and to select the best performing one amongst feasible candidate alternatives.

2.2.8 Concluding Remarks

Supply chain management is the backbone of corporate production, operation and streamlined towards facing market competition. Performance evaluation of supply chain provides a momentous and strategic guidance for the effective implementation of supply chain management. Aforesaid work entitled multiple subjective evaluation indices for the evaluation of supply chain performance. Due to inherent vagueness, inconsistency and incompleteness associated with decision-makers (expert panel) commitment towards assessment of various evaluation indices, this work explored an interval-valued fuzzy set theory combined with MULTIMOORA method to facilitate solution of the said decision-making problem. The theory of dominance has been applied in the proposed evaluation model which summarized the ranking orders provided by different parts of MULTIMOORA, namely the Ratio System, the Reference Point, and the Full Multiplicative Form and finally, the result revealed the most suitable alternative in perspective of supply chain performance. The main contributions of the aforesaid research have been highlighted below.

1. Exploration of fuzzy integrated MOORA method towards evaluation-selection and benchmarking of supply chain performances of alternative industries.
2. Adaptation of fuzzy logic to tackle subjective evaluation information.
3. Apart from manufacturing industry/production unit the proposed appraisement module can be applied to any service sector/their supply chain to monitor performance extent of the supply chain.

Table 2.18: Nine-member linguistic terms and their corresponding interval-valued fuzzy numbers

Linguistic terms for weight assignment	Linguistic terms for ratings	Interval-Valued trapezoidal fuzzy numbers
Absolutely low, AL	Absolutely poor, AP	[(0.0, 0.0, 0.0, 0.0; 1.0), (0.0, 0.0, 0.0, 0.0; 1.0)]
Very low, VL	Very poor, VP	[(0.0075, 0.0075, 0.015, 0.0525; 0.5), (0.0, 0.0, 0.02, 0.07; 1.0)]
Low, L	Poor, P	[(0.0875, 0.12, 0.16, 0.1825; 0.5), (0.04, 0.10, 0.18, 0.23; 1.0)]
Fairly low, FL	Fairly poor, FP	[(0.2325, 0.255, 0.325, 0.3575; 0.5), (0.17, 0.22, 0.36, 0.42; 1.0)]
Medium, M	Medium, M	[(0.4025, 0.4525, 0.5375, 0.5676; 0.5), (0.32, 0.41, 0.58, 0.65; 1.0)]
Fairly High, FH	Fairly satisfactory, FS	[(0.65, 0.6725, 0.7575, 0.79; 0.5), (0.58, 0.63, 0.80, 0.86; 1.0)]
High, H	Satisfactory, S	[(0.7825, 0.815, 0.885, 0.9075; 0.5), (0.72, 0.78, 0.92, 0.97; 1.0)]
Very High, VH	Very Impressive, VI	[(0.9475, 0.985, 0.9925, 0.9925; 0.5), (0.93, 0.98, 1.0, 1.0; 1.0)]
Absolutely high, AH	Absolutely impressive, AI	[(1.0, 1.0, 1.0, 1.0; 1.0), (1.0, 1.0, 1.0, 1.0; 1.0)]

Table 2.19: Priority weight (in linguistic scale) of 4th level indices assigned by DMs

4th level indices	Priority weight (in linguistic scale) of 4th level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	VH	VH	H	VH	VH
C_{1211}	FH	FH	H	H	H
C_{1311}	AH	VH	AH	AH	AH
C_{1321}	M	FH	FH	FH	M
C_{1322}	AH	H	H	H	H
C_{1331}	VH	VH	H	VH	VH
C_{1332}	H	FH	H	H	H
C_{2111}	AH	VH	AH	AH	AH
C_{2211}	M	H	FH	FH	M
C_{2221}	AH	H	H	H	H
C_{2231}	VH	VH	H	VH	VH

C_{2241}	FH	FH	H	H	H
C_{2311}	AH	VH	H	AH	AH
C_{2411}	M	FH	FH	H	M
C_{3111}	AH	H	H	H	H
C_{3121}	VH	VH	H	VH	VH
C_{3131}	FH	FH	H	H	H
C_{3141}	AH	H	AH	AH	AH
C_{3151}	M	FH	FH	FH	M
C_{3211}	AH	H	H	H	H
C_{3311}	VH	VH	H	VH	VH
C_{3411}	FH	H	H	H	H
C_{4111}	AH	VH	AH	AH	AH
C_{4211}	M	FH	FH	FH	M
C_{4221}	AH	H	H	H	H
C_{4231}	VH	VH	H	VH	VH
C_{4241}	FH	FH	H	H	H
C_{4251}	AH	VH	AH	H	AH
C_{4311}	M	H	FH	FH	M
C_{5111}	AH	H	H	H	H
C_{5121}	VH	VH	H	VH	VH
C_{5131}	FH	H	H	H	H
C_{5132}	AH	VH	AH	H	AH
C_{5141}	M	FH	FH	FH	M
C_{5142}	AH	H	H	H	H
C_{5211}	VH	VH	H	VH	VH

Table 2.20: Priority weight (in linguistic scale) of 3rd level indices assigned by DMs

3rd level indices	Priority weight (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{111}	VH	VH	H	VH	VH
C_{121}	FH	FH	H	H	H
C_{131}	AH	VH	AH	AH	AH
C_{132}	AH	VH	H	AH	AH
C_{133}	M	FH	FH	H	M
C_{211}	AH	VH	AH	AH	AH
C_{221}	M	H	FH	FH	M
C_{222}	AH	H	H	H	H
C_{223}	VH	VH	H	VH	VH
C_{224}	FH	FH	H	H	H
C_{231}	AH	VH	H	AH	AH
C_{241}	M	FH	FH	H	M
C_{311}	AH	H	H	H	H
C_{312}	VH	VH	H	VH	VH
C_{313}	FH	FH	H	H	H
C_{314}	AH	H	AH	AH	AH
C_{315}	M	FH	FH	FH	M
C_{321}	AH	H	H	H	H
C_{331}	VH	VH	H	VH	VH
C_{341}	FH	H	H	H	H
C_{411}	AH	VH	AH	AH	AH
C_{421}	M	FH	FH	FH	M
C_{422}	AH	H	H	H	H
C_{423}	VH	VH	H	VH	VH
C_{424}	FH	FH	H	H	H
C_{425}	AH	VH	AH	H	AH
C_{431}	M	H	FH	FH	M
C_{511}	AH	H	H	H	H
C_{512}	VH	VH	H	VH	VH
C_{513}	AH	VH	AH	AH	AH
C_{514}	M	FH	FH	FH	M
C_{521}	VH	VH	H	VH	VH

Table 2.21: Priority weight (in linguistic scale) of 2nd level indices assigned by DMs

2nd Level indices	Priority weight (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{11}	VH	VH	H	VH	VH
C_{12}	FH	FH	H	H	H
C_{13}	FH	FH	H	H	H
C_{21}	AH	VH	AH	AH	AH
C_{22}	M	FH	FH	H	M
C_{23}	AH	VH	H	AH	AH
C_{24}	M	FH	FH	H	M
C_{31}	FH	FH	H	H	H
C_{32}	AH	H	H	H	H
C_{33}	VH	VH	H	VH	VH
C_{34}	FH	H	H	H	H
C_{41}	AH	VH	AH	AH	AH
C_{42}	FH	H	H	H	H
C_{43}	M	H	FH	FH	M
C_{51}	M	FH	FH	FH	M
C_{52}	VH	VH	H	VH	VH

Table 2.22: Priority weight (in linguistic scale) of 1st level indices assigned by DMs

1st level indices	Priority weight (in linguistic scale) of 1st level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_1	H	H	AH	H	H
C_2	H	VH	VH	VH	VH
C_3	FH	FH	H	H	H
C_4	H	VH	H	AH	AH
C_5	M	FH	H	H	M

Table 2.23: Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs (Alternative A_1)

4th level indices	Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	S	S	FS	FS	S
C_{1211}	VI	S	VI	VI	VI
C_{1311}	AI	AI	VI	VI	VI
C_{1321}	M	FS	M	M	M
C_{1322}	FP	M	M	M	M
C_{1331}	S	S	FS	S	S
C_{1332}	S	VI	VI	S	S
C_{2111}	M	FS	S	S	M
C_{2211}	S	FS	FS	FS	S
C_{2221}	FS	FS	FS	FS	FS
C_{2231}	M	FP	FP	FP	FP
C_{2241}	M	M	M	M	M
C_{2311}	FS	M	M	M	M
C_{2411}	VI	S	VI	VI	VI
C_{3111}	S	S	FS	S	S
C_{3121}	M	M	M	FS	FS
C_{3131}	M	M	M	FS	M
C_{3141}	VI	S	VI	VI	VI
C_{3151}	S	FS	FS	FS	S
C_{3211}	FS	FS	FS	FS	FS

C_{3311}	M	FP	FP	FP	FP
C_{3411}	M	M	M	M	M
C_{4111}	FS	FS	M	M	M
C_{4211}	S	S	VI	VI	VI
C_{4221}	M	FS	S	S	M
C_{4231}	S	FS	FS	FS	S
C_{4241}	FS	FS	FS	FS	FS
C_{4251}	M	FP	FP	FP	FP
C_{4311}	M	M	M	M	M
C_{5111}	FS	FS	M	M	M
C_{5121}	VI	S	VI	VI	VI
C_{5131}	M	S	S	S	M
C_{5132}	S	FS	S	FS	S
C_{5141}	FS	FS	FS	FS	FS
C_{5142}	M	FP	FP	FP	FP
C_{5211}	M	M	FS	M	M

Table 2.24: Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs **(Alternative A_2)**

4th level indices	Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	FP	M	M	FP	M
C_{1211}	M	FS	M	FS	FS
C_{1311}	FS	S	S	S	S
C_{1321}	VI	VI	S	S	S
C_{1322}	S	S	S	S	S
C_{1331}	P	P	FP	FP	FP
C_{1332}	M	M	M	M	M
C_{2111}	S	VI	VI	S	S
C_{2211}	FP	M	FS	M	M
C_{2221}	M	M	M	M	M
C_{2231}	S	S	S	VI	S

C_{2241}	M	M	M	FP	M
C_{2311}	M	FS	M	FS	FS
C_{2411}	FS	S	S	S	S
C_{3111}	VI	VI	VI	S	S
C_{3121}	S	S	S	S	S
C_{3131}	P	P	FP	FP	FP
C_{3141}	M	M	M	M	M
C_{3151}	S	VI	VI	S	S
C_{3211}	M	M	FS	M	M
C_{3311}	M	M	M	M	M
C_{3411}	S	S	S	VI	S
C_{4111}	FP	M	M	FP	M
C_{4211}	M	FS	M	FS	FS
C_{4221}	FS	S	S	S	S
C_{4231}	VI	VI	S	S	S
C_{4241}	S	S	S	S	S
C_{4251}	P	P	M	FP	FP
C_{4311}	M	M	M	M	M
C_{5111}	S	VI	VI	S	S
C_{5121}	FP	M	FP	M	M
C_{5131}	M	M	M	M	M
C_{5132}	S	S	S	VI	S
C_{5141}	FP	M	M	P	M
C_{5142}	M	FS	M	FS	FS
C_{5211}	FS	S	S	VI	FS

Table 2.25: Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs **(Alternative A_3)**

4th level indices	Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_{1111}	AI	AI	AI	VI	VI
C_{1211}	S	VI	VI	VI	VI
C_{1311}	FS	S	S	S	S
C_{1321}	S	S	S	VI	VI
C_{1322}	M	M	M	M	M
C_{1331}	FS	S	FS	S	FS
C_{1332}	FP	M	M	M	M
C_{2111}	FS	S	FS	FS	FS
C_{2211}	P	FP	M	M	FS
C_{2221}	S	S	VI	VI	S
C_{2231}	P	P	FP	P	FP
C_{2241}	VI	AI	AI	VI	VI
C_{2311}	S	VI	VI	VI	VI
C_{2411}	FS	S	S	S	S
C_{3111}	S	S	S	VI	VI
C_{3121}	M	FS	M	M	M
C_{3131}	FS	S	FS	S	FS
C_{3141}	FP	M	M	M	M
C_{3151}	FS	S	FS	FS	FS
C_{3211}	P	FP	FS	M	FS
C_{3311}	S	S	VI	VI	S
C_{3411}	P	P	FP	P	FP
C_{4111}	AI	AI	AI	VI	VI
C_{4211}	S	VI	S	VI	VI
C_{4221}	FS	S	S	FS	S
C_{4231}	S	S	S	VI	VI
C_{4241}	M	M	M	M	M
C_{4251}	FS	S	FS	S	FS
C_{4311}	FP	M	M	M	M
C_{5111}	FS	S	FS	FS	FS
C_{5121}	P	FP	M	M	FS

C_{5131}	S	S	S	VI	S
C_{5132}	P	FP	FP	FP	FP
C_{5141}	AI	AI	AI	VI	VI
C_{5142}	S	VI	VI	VI	VI
C_{5211}	FS	FS	S	S	S

Table 2.26: Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 4th level indices **(Alternative A_1)**

4th level indices	Aggregated fuzzy appropriateness rating, U_{ijkl}	Aggregated fuzzy priority weight, w_{ijkl}
C_{1111}	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{1211}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{1311}	[(0.9685,0.9910,0.9955,0.9955;0.5000), (0.9580,0.9880,1.0000,1.0000;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{1321}	[(0.4520,0.4965,0.5815,0.6121;0.5000), (0.3720,0.4540,0.6240,0.6920;1.000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{1322}	[(0.3685,0.4130,0.4950,0.5256;0.5000), (0.2900,0.3720,0.5360,0.6040;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{1331}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{1332}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{2111}	[(0.6040,0.6415,0.7205,0.7480;0.5000), (0.5320,0.6020,0.7600,0.8200;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{2211}	[(0.7030,0.7295,0.8085,0.8370;0.5000), (0.6360,0.6900,0.8480,0.9040;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{2221}	[(0.6500,0.6725,0.7575,0.7900;0.5000), (0.5800,0.6300,0.8000,0.8600;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.93600.9760;1.0000)]
C_{2231}	[(0.2665,0.2945,0.3675,0.3995;0.5000), (0.2000,0.2580,0.4040,0.4660;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{2241}	[(0.4025,0.4525,0.5375,0.5676;0.5000),	[(0.7295,0.7580,0.8340,0.8605;0.5000),

	(0.3200,0.4100,0.5800,0.6500;1.0000)]	(0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{2311}	[(0.5610,0.6030,0.6725,0.6971;0.5000), (0.4940,0.5680,0.7080,0.7620;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{2411}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{3111}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{3121}	[(0.5015,0.5405,0.6255,0.6566;0.5000), (0.4240,0.4980,0.6680,0.7340;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000) (0.8880,0.9400,0.98400.9940;1.0000)]
C_{3131}	[(0.4520,0.4965,0.5815,0.6121;0.5000), (0.3720,0.4540,0.6240,0.6920;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{3141}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]	[(0.9565,0.9630,0.9770,0.9815;0.5000), (0.9440,0.9560,0.9840,0.9940;1.0000)]
C_{3151}	[(0.7030,0.7295,0.8085,0.8370;0.5000), (0.6360,0.6900,0.8480,0.9040;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{3211}	[(0.6500,0.6725,0.7575,0.7900;0.5000), (0.5800,0.6300,0.8000,0.8600;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{3311}	[(0.2665,0.2945,0.3675,0.3995;0.5000) (0.2000,0.2580,0.4040,0.4660;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{3411}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{4111}	[(0.5015,0.5405,0.6255,0.6566;0.5000), (0.4240,0.4980,0.6680,0.7340;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{4211}	[(0.8815,0.9170,0.9495,0.9585;0.5000), (0.8460,0.9000,0.9680,0.9880;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{4221}	[(0.6040,0.6415,0.7205,0.7480;0.5000), (0.5320,0.6020,0.7600,0.8200;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000) (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{4231}	[(0.7030,0.7295,0.8085,0.8370;0.5000), (0.6360,0.6900,0.8480,0.9040;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{4241}	[(0.6500,0.6725,0.7575,0.7900;0.5000), (0.5800,0.6300,0.8000,0.8600;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{4251}	[(0.2665,0.2945,0.3675,0.3995;0.500), (0.2000,0.2580,0.4040,0.4660;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{4311}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]

C_{5111}	[(0.5015,0.5405,0.6255,0.6566;0.5000), (0.4240,0.4980,0.6680,0.7340;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{5121}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.000)]	[(0.9145,0.9510,0.97100.9755;0.5000), (0.8880,0.9400,0.9840,0.9940; 1.0000)]
C_{5131}	[(0.6305,0.6700,0.7460,0.7715;0.500), (0.5600,0.6320,0.7840,0.8420;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{5132}	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{5141}	[(0.6500,0.6725,0.7575,0.7900;0.5000), (0.5800,0.6300,0.8000,0.8600;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{5142}	[(0.2665,0.2945,0.3675,0.3995;0.500), (0.2000,0.2580,0.4040,0.4660;1.000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{5211}	[(0.4520,0.4965,0.5815,0.6121;0.5000), (0.3720,0.4540,0.6240,0.6920;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.27: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 3rd level indices **(Alternative A_1)**

3rd level indices	Computed fuzzy appropriateness rating, U_{ijk}	Aggregated fuzzy priority weight, w_{ijk}
C_{111}	[(0.6839,0.74240.8515,0.9179;0.5000), (0.5932,0.6878,0.9128,1.0365;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{121}	[(0.7753,0.8643,1.0684,1.1507;0.5000), (0.6368,0.7761,1.1917,1.3862;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{131}	[(0.9598,0.9895,0.9970,1.0046;0.5000), (0.9446,0.9840,1.0040,1.0142;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{132}	[(0.3401,0.4070,0.5839,0.6651;0.5000), (0.2295,0.3353,0.6925,0.8998;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{133}	[(0.7168,0.7880,0.9394,1.0144;0.5000), (0.6029,0.7181,1.0264,1.1856;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{211}	[(0.5986,0.6405,0.7216,0.7548;0.5000), (0.5246,0.5996,0.7631,0.8316;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{221}	[(0.5603,0.6434,0.9167,1.0501;0.5000), (0.4017,0.5363,1.0911,1.4313;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{222}	[(0.5798,0.6310,0.8073,0.8856;0.5000),	[(0.8260,0.8520,0.9080,0.9260;0.5000),

	(0.4611,0.5546,0.9087,1.0816;1.0000)]	(0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{223}	[(0.2498,0.2884,0.3752,0.4262;0.5000), (0.1787,0.2465,0.4229,0.5216;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{224}	[(0.3412,0.4113,0.5914,0.6695;0.5000), (0.2295,0.3385,0.7024,0.9065;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{231}	[(0.5415,0.5934,0.6834,0.7221;0.5000), (0.4622,0.5495,0.7318,0.8144;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{241}	[(0.7289,0.8388,1.1009,1.2239;0.5000), (0.5608,0.7305,1.2661,1.5738;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{311}	[(0.6744,0.7380,0.9160,0.9910;0.5000), (0.5502,0.6603,1.0178,1.1923;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{312}	[(0.4701,0.5294,0.6387,0.7004;0.5000), (0.3788,0.4757,0.6993,0.8216;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{313}	[(0.3832,0.4513,0.6398,0.7220;0.5000), (0.2667,0.3749,0.7557,0.9650;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{314}	[(0.8912,0.9374,0.9851,1.0010;0.5000), (0.8433,0.9133,1.0128,1.0466;1.0000)]	[(0.9565,0.9630,0.9770,0.9815;0.5000), (0.9440,0.9560,0.9840,0.9940;1.0000)]
C_{315}	[(0.5525,0.6369,0.9261,1.0649;0.5000), (0.3901,0.5253,1.1140,1.4737;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{321}	[(0.5798,0.6310,0.8073,0.8856;0.5000), (0.4611,0.5546,0.9087,1.0816;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{331}	[(0.2498,0.2884,0.3752,0.4262;0.5000), (0.1787,0.2465,0.4229,0.5216;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{341}	[(0.3442,0.4141,0.5874,0.6637;0.5000), (0.2336,0.3432,0.6929,0.8905;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{411}	[(0.4970,0.5397,0.6264,0.6625;0.5000), (0.4181,0.4960,0.6707,0.7444;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{421}	[(0.6928,0.8006,1.0876,1.2195;0.5000), (0.5189,0.6851,1.2716,1.6107;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{422}	[(0.5388,0.6019,0.7679,0.8386;0.5000), (0.4230,0.5300,0.8633,1.0313;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{423}	[(0.6590,0.7145,0.8255,0.8928;0.5000), (0.5682,0.6591,0.8877,1.0119;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{424}	[(0.5510,0.6112,0.8334,0.9319;0.5000), (0.4159,0.5202,0.9689,1.1993;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{425}	[(0.2573,0.2898,0.3734,0.4139;0.5000),	[(0.9460,0.96000.9755,0.9800;0.5000),

	(0.1871,0.2496,0.4176,0.4981;1.0000)]	(0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{431}	[(0.3208,0.3991,0.6094,0.7121;0.5000), (0.2021,0.3186,0.7463,1.0292;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{511}	[(0.4473,0.5072,0.6666,0.7360;0.5000), (0.3371,0.4384,0.7588,0.9232;1.0000)]	[(0.82600.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.93600.9760;1.0000)]
C_{512}	[(0.8573,0.9314,0.9914,1.0406;0.5000), (0.7933,0.8980,1.0301,1.1127;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{513}	[(0.6259,0.6837,0.8330,0.8962;0.5000), (0.5175,0.6167,0.9169,1.0596;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{514}	[(0.3554,0.4082,0.5853,0.6709;0.5000), (0.2462,0.3362,0.6938,0.8963;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{521}	[(0.4237,0.4863,0.5937,0.6529;0.5000), (0.3323,0.4337,0.6532,0.7746;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.28: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 2nd level indices **(Alternative A_1)**

2nd Level indices	Computed fuzzy appropriateness rating, U_{ij}	Aggregated fuzzy priority weight, w_{ij}
C_{11}	[(0.6411,0.7271,0.8694,0.9791;0.5000), (0.5299,0.6570,0.9555,1.1603;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{12}	[(0.6573,0.7856,1.1755,1.3573;0.5000), (0.4566,0.6409,1.4433,1.9332;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000) (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{13}	[(0.6235,0.6970,0.8630,0.9510;0.5000), (0.5189,0.6287,0.9686,1.1796;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{21}	[(0.5932,0.6396,0.7227,0.7617;0.5000), (0.5172,0.5972,0.7661,0.8435;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000) (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{22}	[(0.7590,0.6389,0.7549,0.6301;0.5000), (0.3098,0.7261,1.0079,1.3089;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{23}	[(0.5227,0.5840,0.6944,0.7481;0.5000), (0.4324,0.5317,0.7564,0.8705;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{24}	[(0.5810,0.7398,1.2482,1.5355;0.5000), (0.3542,0.5678,1.6291,2.4919;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{31}	[(0.5453,0.6306,0.8684,0.9934;0.5000), (0.4120,0.5390,1.0270,1.3495;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]

C_{32}	[(0.5172,0.5921,0.8603,0.9929;0.5000), (0.3667,0.4883,1.0323,1.3604;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{33}	[(0.2342,0.2825,0.3831,0.4546;0.5000), (0.1596,0.2354,0.4427,0.5839;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{34}	[(0.2944,0.3789,0.6419,0.7761;0.5000), (0.1705,0.2873,0.8278,1.2199;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{41}	[(0.4925,0.5389,0.6274,0.6686;0.5000), (0.4122,0.4940,0.6734,0.7550;1.0000)]	[(0.9895,0.9970,0.9985,0.99850;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{42}	[(0.4670,0.5511,0.8005,0.9352;0.5000), (0.3279,0.4545,0.9660,1.3037;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{43}	[(0.2557,0.3520,0.6909,0.8934;0.5000), (0.1276,0.2476,0.9603,1.6295;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{51}	[(0.5467,0.6310,0.8248,0.9332;0.5000), (0.4254,0.5512,0.9493,1.2035;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{52}	[(0.3972,0.4763,0.6062,0.6965;0.5000), (0.2969,0.4143,0.6838,0.8671;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.29: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 1nd level indices **(Alternative A_1)**

1nd Level indices	Computed fuzzy appropriateness rating, U_{ij}	Aggregated fuzzy priority weight, w_{ij}
C_1	[(0.5639,0.6879,1.0314,1.2393;0.5000), (0.3929,0.5615,1.2788,1.8212;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_2	[(0.5413,0.6075,0.8769,0.9910;0.5000), (0.3473,0.5327,1.1162,1.6217;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_3	[(0.3460,0.4336,0.7257,0.9001;0.5000), (0.2127,0.3327,0.9397,1.4286;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_4	[(0.3790,0.4647,0.7489,0.9219;0.5000), (0.2541,0.3703,0.9688,1.5084;1.0000)]	[(0.9025,0.9230,0.9525,0.9615;0.5000), (0.8740,0.9080,0.9680,0.9880;1.0000)]
C_5	[(0.3964,0.5009,0.7430,0.9100;0.5000), (0.2633,0.4058,0.9101,1.3166;1.0000)]	[(0.60400.6415,0.7205,0.7480;0.5000), (0.5320,0.6020,0.7600,0.8200;1.0000)]

Table 2.30: Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 4th level indices **(Alternative A_2)**

4^{th} level indices	Aggregated fuzzy appropriateness rating, U_{ijkl}	Aggregated fuzzy priority weight, w_{ijkl}
C_{1111}	[(0.3345,0.3735,0.4525,0.4836;0.5000), (0.2600,0.3340,0.4920,0.5580;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{1211}	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{1311}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.75000.8960,0.9480;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{1321}	[(0.8485,0.88300.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{1322}	[(0.7825,0.8150,0.8850,0.9075;0.5000), (0.7200,0.7800,0.9200,0.9700;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{1331}	[(0.1745,0.2010,0.2590,0.2875;0.5000), (0.1180,0.1720,0.2880,0.3440;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{1332}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.41000.5800,0.6500;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{2111}	[(0.7395,0.7765,0.8370,0.8565;0.5000), (0.6820,0.7460,0.8680,0.9120;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{2211}	[(0.4180,0.4570,0.5390,0.5701;0.5000), (0.3420,0.4160,0.5800,0.6460;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{2221}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.93600.9760;1.0000)]
C_{2231}	[(0.8155,0.8490,0.90650.9245;0.5000), (0.7620,0.8200,0.9360,0.9760;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{2241}	[(0.3685,0.4130,0.4950,0.5256;0.5000), (0.2900,0.3720,0.5360,0.6040;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{2311}	[(0.5510,0.5845,0.66950.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{2411}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{3111}	[(0.8815,0.9170,0.9495,0.9585;0.5000), (0.8460,0.9000,0.96800.9880;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]

C_{3121}	[(0.7825,0.8150,0.8850,0.9075;0.5000), (0.7200,0.7800,0.9200,0.9700;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.98400.9940;1.0000)]
C_{3131}	[(0.1745,0.2010,0.2590,0.2875;0.5000), (0.1180,0.1720,0.2880,0.3440;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{3141}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.9565,0.9630,0.9770,0.9815;0.5000), (0.9440,0.9560,0.9840,0.9940;1.0000)]
C_{3151}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{3211}	[(0.4520,0.4965,0.5815,0.6121;0.5000), (0.3720,0.4540,0.6240,0.6920;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{3311}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{3411}	[(0.8155,0.8490,0.9065,0.9245;0.5000), (0.7620,0.8200,0.9360,0.9760;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{4111}	[(0.3345,0.3735,0.4525,0.4836;0.5000), (0.2600,0.3340,0.4920,0.5580;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{4211}	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{4221}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{4231}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{4241}	[(0.7825,0.8150,0.8850,0.9075;0.5000), (0.7200,0.7800,0.9200,0.9700;1.00000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{4251}	[(0.2085,0.2405,0.3015,0.3295;0.5000), (0.1480,0.2100,0.3320,0.3900;1.00000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{4311}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{5111}	[(0.8485,0.8830,0.92800.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{5121}	[(0.3345,0.3735,0.4525,0.4836;0.5000), (0.2600,0.3340,0.4920,0.5580;1.0000)]	[(0.9145,0.9510,0.97100.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{5131}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{5132}	[(0.8155,0.8490,0.9065,0.9245;0.5000), (0.7620,0.8200,0.9360,0.9760;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]

C_{5141}	[(0.3055,0.3465,0.4195,0.4486;0.5000), (0.2340,0.3100,0.4560,0.5200;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{5142}	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{5211}	[(0.7625,0.7920,0.8555,0.8775;0.5000), (0.7060,0.7600,0.8880,0.9320;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.31: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 3^{rd} level indices **(Alternative A_2)**

3^{rd} level indices	Computed fuzzy appropriateness rating, U_{ijk}	Aggregated fuzzy priority weight, w_{ijk}
C_{111}	[(0.3136,0.3658,0.4620,0.5158;0.5000), (0.2323,0.3191,0.5150,0.6246;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{121}	[(0.4671,0.5312,0.7366,0.8269;0.5000), (0.3413,0.4475,0.8623,1.0822;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{131}	[(0.7492,0.7853,0.8608,0.8920;0.5000), (0.6823,0.7470,0.8996,0.9615;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{132}	[(0.6846,0.7673,0.9919,1.0896;0.5000), (0.5373,0.6728,1.1266,1.3648;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{133}	[(0.2495,0.2988,0.4106,0.4683;0.5000), (0.1680,0.2496,0.47520.6064;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{211}	[(0.7328,0.7753,0.8383,0.8643;0.5000), (0.6725,0.7430,0.8715,0.9249;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{221}	[(0.3332,0.4031,0.6111,0.7152;0.5000), (0.2160,0.3233,0.7463,1.0228;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{222}	[(0.3590,0.4246,0.5728,0.6363;0.5000), (0.2544,0.3609,0.6588,0.8175;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{223}	[(0.7645,0.8315,0.9256,0.9862;0.5000), (0.6807,0.7833,0.9798,1.0925;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{224}	[(0.3124,0.3754,0.5446,0.6200;0.5000), (0.2079,0.3072,0.6492,0.8423;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{231}	[(0.5319,0.5752,0.6803,0.7262;0.5000), (0.4454,0.5244,0.7359,0.8294;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]

C_{241}	[(0.6026,0.6937,0.9745,1.1091;0.5000), (0.4371,0.5829,1.1529,1.5010;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{311}	[(0.7863,0.8604,1.0119,1.0745;0.5000), (0.6726,0.7923,1.0996,1.2426;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{312}	[(0.7336,0.7982,0.9036,0.9680;0.5000), (0.6432,0.7451,0.9631,1.0858;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{313}	[(0.1479,0.1827,0.2850,0.3391;0.5000), (0.0846,0.1420,0.3488,0.4797;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{314}	[(0.3922,0.4460,0.5453,0.5824;0.5000), (0.3039,0.3983,0.5970,0.6844;1.0000)]	[(0.9565,0.9630,0.9770,0.9815;0.5000), (0.9440,0.9560,0.9840,0.9940;1.0000)]
C_{315}	[(0.6669,0.7709,1.0630,1.1979;0.5000), (0.4932,0.6547,1.2506,1.6009;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{321}	[(0.4032,0.4659,0.6197,0.6862;0.5000), (0.2958,0.3997,0.7088,0.8704;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{331}	[(0.3773,0.4432,0.5488,0.6055;0.5000), (0.2859,0.3917,0.6071,0.7276;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{341}	[(0.6974,0.7769,0.9906,1.0810;0.5000), (0.5562,0.6864,1.1182,1.3371;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{411}	[(0.3315,0.3729,0.4532,0.4880;0.5000), (0.2564,0.3327,0.4940,0.5659;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{421}	[(0.4331,0.5103,0.7669,0.8919;0.5000), (0.2920,0.4126,0.9353,1.2651;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{422}	[(0.6744,0.7380,0.9160,0.9910;0.5000), (0.5502,0.66031.0178,1.1923;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{423}	[(0.7954,0.8648,0.9475,1.0043;0.5000), (0.7183,0.8215,0.9966,1.0992;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{424}	[(0.6634,0.7407,0.9737,1.0705;0.5000), (0.5163,0.6440,1.1142,1.3527;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{425}	[(0.2013,0.2367,0.3064,0.3414;0.5000), (0.1385,0.2032,0.3432,0.4168;1.0000)]	[(0.9460,0.96000.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{431}	[(0.3208,0.3991,0.6094,0.7121;0.5000), (0.2021,0.31860.7463,1.0292;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{511}	[(0.7569,0.8285,0.9890,1.0555;0.5000), (0.6392,0.7571,1.0814,1.2351;1.0000)]	[(0.82600.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.93600.9760;1.0000)]
C_{512}	[(0.3136,0.3658,0.4620,0.5158;0.5000), (0.2323,0.3191,0.5150,0.6246;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

C_{513}	[(0.5771,0.6381,0.7708,0.8271;0.5000), (0.4789,0.5788,0.8465,0.9780;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{514}	[(0.3832,0.4441,0.6187,0.6998;0.5000), (0.2744,0.3730,0.7256,0.9272;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{521}	[(0.7148,0.7757,0.8735,0.9360;0.5000) (0.6307,0.7260,0.9296,1.0433;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.32: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 2nd level indices **(Alternative A_2)**

2nd Level indices	Computed fuzzy appropriateness rating, U_{ij}	Aggregated fuzzy priority weight, w_{ij}
C_{11}	[(0.2940,0.3583,0.4717,0.5502;0.5000), (0.2075,0.3048,0.5391,0.6992;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{12}	[(0.3960,0.4828,0.8105,0.9754;0.5000), (0.2447,0.3695,1.0444,1.5092;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{13}	[(0.5671,0.6380,0.8220,0.9144;0.5000), (0.4503,0.5615,0.9357,1.1579;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{21}	[(0.7262,0.7742,0.8395,0.8722;0.5000), (0.6630,0.7400,0.8750,0.9381;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{22}	[(0.8421,0.6590,0.7638,0.6301;0.5000), (0.3600,0.7299,0.9864,1.3089;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{23}	[(0.5134,0.5661,0.6913,0.7523;0.5000), (0.4167,0.5073,0.7607,0.8865;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{24}	[(0.4803,0.6119,1.1048,1.3915;0.5000), (0.2760,0.4530,1.4834,2.3766;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{31}	[(0.4884,0.5759,0.7979,0.9158;0.5000), (0.3581,0.4882,0.9440,1.2430;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{32}	[(0.3596,0.4371,0.6605,0.7693;0.5000), (0.2352,0.3519,0.8052,1.0947;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{33}	[(0.3537,0.4341,0.5603,0.6458;0.5000), (0.2554,0.3742,0.6356,0.8144;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{34}	[(0.5964,0.7109,1.0826,1.2641;0.5000), (0.4060,0.5745,1.3359,1.8317;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]

C_{41}	[(0.3285,0.3724,0.4539,0.4924;0.5000), (0.2528,0.3313,0.4960,0.5740;1.0000)]	[(0.9895,0.9970,0.9985,0.99850;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{42}	[(0.4946,0.5824,0.8223,0.9524;0.5000), (0.3591,0.4895,0.9825,1.3136;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{43}	[(0.2557,0.3520,0.6909,0.8934;0.5000), (0.1276,0.2476,0.9603,1.6295;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{51}	[(0.4705,0.5496,0.7477,0.8525;0.5000), (0.3484,0.4687,0.8728,1.1273;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{52}	[(0.6701,0.7597,0.8919,0.9985;0.5000), (0.5635,0.6936,0.9731,1.1678;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.33: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 1nd level indices **(Alternative A_2)**

1nd Level indices	Computed fuzzy appropriateness rating, U_{ij}	Aggregated fuzzy priority weight, w_{ij}
C_1	[(0.3603,0.4510,0.7375,0.9113;0.5000), (0.2269,0.3508,0.9484,1.4281;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_2	[(0.5742,0.6226,0.8832,0.9943;0.5000), (0.3793,0.5488,1.1130,1.6280;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_3	[(0.3916,0.4985,0.8184,1.0068;0.5000), (0.2414,0.3861,1.0511,1.5780;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_4	[(0.3247,0.4094,0.6844,0.8528;0.5000), (0.2047,0.3187,0.8986,1.4297;1.0000)]	[(0.9025,0.9230,0.9525,0.9615;0.5000), (0.8740,0.9080,0.9680,0.9880;1.0000)]
C_5	[(0.5201,0.6362,0.8900,1.0724;0.5000), (0.3764,0.5342,1.0654,1.4923;1.0000)]	[(0.60400.6415,0.7205,0.7480;0.5000), (0.5320,0.6020,0.7600,0.8200;1.0000)]

Table 2.34: Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 4th level indices **(Alternative A_3)**

4^{th} level indices	Aggregated fuzzy appropriateness rating, U_{ijkl}	Aggregated fuzzy priority weight, w_{ijkl}
C_{1111}	[(0.9790,0.9940,0.9970,0.9970;0.5000), (0.9720,0.9920,1.0000,1.0000;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{1211}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{1311}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{1321}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{1322}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{1331}	[(0.7030,0.7295,0.8085,0.8370;0.5000), (0.6360,0.6900,0.8480,0.9040;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{1332}	[(0.3685,0.4130,0.4950,0.5256;0.5000), (0.2900,0.3720,0.5360,0.6040;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{2111}	[(0.6765,0.7010,0.7830,0.8135;0.5000), (0.6080,0.6600,0.8240,0.8820;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{2211}	[(0.3550,0.3905,0.4635,0.4930;0.5000), (0.2860,0.3540,0.5000,0.5620;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{2221}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.93600.9760;1.0000)]
C_{2231}	[(0.1455,0.1740,0.2260,0.2525;0.5000), (0.0920,0.1480,0.2520,0.3060;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{2241}	[(0.9685,0.9910,0.9955,0.9955;0.5000), (0.9580,0.9880,1.0000,1.0000;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{2311}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{2411}	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{3111}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]

C_{3121}	[(0.4520,0.4965,0.5815,0.6121;0.5000), (0.3720,0.4540,0.6240,0.6920;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.98400.9940;1.0000)]
C_{3131}	[(0.7030,0.7295,0.8085,0.8370;0.5000), (0.6360,0.6900,0.8480,0.9040;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{3141}	[(0.3685,0.4130,0.4950,0.5256;0.5000), (0.2900,0.3720,0.5360,0.6040;1.0000)]	[(0.9565,0.9630,0.9770,0.9815;0.5000), (0.9440,0.9560,0.9840,0.9940;1.0000)]
C_{3151}	[(0.6765,0.7010,0.7830,0.8135;0.5000), (0.6080,0.6600,0.8240,0.8820;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{3211}	[(0.4045,0.4345,0.5075,0.5375;0.5000), (0.3380,0.3980,0.5440,0.6040;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{3311}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{3411}	[(0.1455,0.1740,0.2260,0.2525;0.5000), (0.0920,0.1480,0.2520,0.3060;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{4111}	[(0.9790,0.9940,0.9970,0.9970;0.5000), (0.9720,0.9920,1.0000,1.0000;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{4211}	[(0.8815,0.9170,0.9495,0.9585;0.5000), (0.8460,0.9000,0.9680,0.9880;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{4221}	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{4231}	[(0.8485,0.8830,0.9280,0.9415;0.5000), (0.8040,0.8600,0.9520,0.9820;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{4241}	[(0.4025,0.4525,0.5375,0.5676;0.5000), (0.3200,0.4100,0.5800,0.6500;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{4251}	[(0.7030,0.7295,0.8085,0.8370;0.5000), (0.6360,0.6900,0.8480,0.9040;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{4311}	[(0.3685,0.4130,0.4950,0.5256;0.5000), (0.2900,0.3720,0.5360,0.6040;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{5111}	[(0.6765,0.7010,0.7830,0.8135;0.5000), (0.6080,0.6600,0.8240,0.8820;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{5121}	[(0.3550,0.3905,0.4635,0.4930;0.5000), (0.2860,0.3540,0.5000,0.5620;1.0000)]	[(0.9145,0.9510,0.97100.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{5131}	[(0.8155,0.8490,0.9065,0.9245;0.5000), (0.7620,0.8200,0.9360,0.9760;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{5132}	[(0.2035,0.2280,0.2920,0.3225;0.5000), (0.1440,0.1960,0.3240,0.3820;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]

C_{5141}	[(0.9790,0.9940,0.9970,0.9970;0.5000), (0.9720,0.9920,1.0000,1.0000;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{5142}	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{5211}	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.35: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 3rd level indices **(Alternative A_3)**

3rd level indices	Computed fuzzy appropriateness rating, U_{ijk}	Aggregated fuzzy priority weight, w_{ijk}
C_{111}	[(0.9178,0.9735,1.0180,1.0635;0.5000), (0.8683,0.9476,1.0468,1.1194;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{121}	[(0.7753,0.8643,1.0684,1.1507;0.5000), (0.6368,0.7761,1.1917,1.3862;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{131}	[(0.7492,0.7853,0.8608,0.8920;0.5000), (0.6823,0.7470,0.8996,0.9615;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{132}	[(0.4917,0.5716,0.7723,0.8610;0.5000), (0.3602,0.4878,0.8936,1.1154;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{133}	[(0.4956,0.5564,0.6967,0.7669;0.5000), (0.3942,0.4934,0.7779,0.9311;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{211}	[(0.6704,0.6999,0.7842,0.8209;0.5000), (0.5995,0.6574,0.8273,0.8945;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{221}	[(0.2830,0.3444,0.5255,0.6186;0.5000), (0.1806,0.2751,0.6434,0.8898;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{222}	[(0.7569,0.8285,0.9890,1.0555;0.5000), (0.6392,0.7571,1.0814,1.2351;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{223}	[(0.1364,0.1704,0.2308,0.2693;0.5000), (0.0822,0.1414,0.2638,0.3425;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{224}	[(0.8211,0.9007,1.0953,1.1743;0.5000), (0.6869,0.8158,1.2111,1.3946;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{231}	[(0.8828,0.9359,0.9867,1.0106;0.5000), (0.8308,0.9094,1.0171,1.0624;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]

C_{241}	[(0.6026,0.6937,0.9745,1.1091;0.5000), (0.4371,0.5829,1.1529,1.5010;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{311}	[(0.7569,0.8285,0.9890,1.0555;0.5000), (0.6392,0.7571,1.0814,1.2351;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{312}	[(0.4237,0.4863,0.5937,0.6529;0.5000), (0.3323,0.4337,0.6532,0.7746;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{313}	[(0.5960,0.6630,0.8896,0.9873;0.5000), (0.4561,0.5697,1.0270,1.2607;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{314}	[(0.3591,0.4071,0.5022,0.5393;0.5000), (0.2754,0.3614,0.5517,0.6360;1.0000)]	[(0.9565,0.9630,0.9770,0.9815;0.5000), (0.9440,0.9560,0.9840,0.9940;1.0000)]
C_{315}	[(0.5317,0.6120,0.8969,1.0350;0.5000), (0.3729,0.5024,1.0825,1.4379;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{321}	[(0.3608,0.4077,0.5409,0.6026;0.5000), (0.2687,0.3504,0.6179,0.7597;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{331}	[(0.7954,0.8648,0.9475,1.0043;0.5000), (0.7183,0.8215,0.9966,1.0992;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{341}	[(0.1244,0.1592,0.2470,0.2953;0.5000), (0.0672,0.1239,0.3011,0.4192;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{411}	[(0.9702,0.9925,0.9985,1.0061;0.5000), (0.9584,0.9880,1.0040,1.0142;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{421}	[(0.6928,0.8006,1.0876,1.2195;0.5000), (0.5189,0.6851,1.2716,1.6107;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{422}	[(0.6507,0.7113,0.8888,0.9647;0.5000), (0.5279,0.6338,0.9905,1.1647;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{423}	[(0.7954,0.8648,0.9475,1.0043;0.5000), (0.7183,0.8215,0.9966,1.0992;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{424}	[(0.3412,0.4113,0.5914,0.6695;0.5000), (0.2295,0.3385,0.7024,0.9065;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{425}	[(0.6786,0.7179,0.8216,0.8671;0.5000), (0.5951,0.6676,0.8765,0.9662;1.0000)]	[(0.9460,0.96000.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{431}	[(0.2937,0.3643,0.5612,0.6594;0.5000), (0.1832,0.2891,0.6897,0.9563;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{511}	[(0.6034,0.6578,0.8345,0.9120;0.5000), (0.4834,0.5810,0.9360,1.1093;1.0000)]	[(0.82600.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.93600.9760;1.0000)]
C_{512}	[(0.3328,0.3825,0.4732,0.5259;0.5000), (0.2555,0.3382,0.5234,0.6291;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

C_{513}	[(0.4340,0.4832,0.6092,0.6659;0.5000), (0.3405,0.4264,0.6801,0.8045;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{514}	[(0.7958,0.8819,1.0784,1.1636;0.5000), (0.6574,0.7963,1.1955,1.3947;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{521}	[(0.7148,0.7757,0.8735,0.9360;0.5000), (0.6307,0.7260,0.9296,1.0433;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.36: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 2nd level indices **(Alternative A_3)**

2nd Level indices	Computed fuzzy appropriateness rating, U_{ij}	Aggregated fuzzy priority weight, w_{ij}
C_{11}	[(0.8604,0.9535,1.0394,1.1344;0.5000), (0.7757,0.9053,1.0958,1.2530;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{12}	[(0.6573,0.7856,1.1755,1.3573;0.5000), (0.4566,0.6409,1.4433,1.9332;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{13}	[(0.5522,0.6267,0.8160,0.9113;0.5000), (0.4321,0.5480,0.9331,1.1625;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{21}	[(0.6644,0.6989,0.7854,0.8284;0.5000), (0.5911,0.6547,0.8306,0.9072;1.0000)]	[(0.9895,0.9970,0.9985,0.9985;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{22}	[(0.8809,0.6886,0.7919,0.6301;0.5000), (0.3754,0.7584,1.0055,1.3089;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{23}	[(0.8521,0.9210,1.0026,1.0469;0.5000), (0.7773,0.8799,1.0513,1.1355;1.0000)]	[(0.9460,0.9600,0.9755,0.9800;0.5000), (0.9300,0.9520,0.9840,0.9940;1.0000)]
C_{24}	[(0.4803,0.6119,1.1048,1.3915;0.5000), (0.2760,0.45301.4834,2.3766;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{31}	[(0.4689,0.5553,0.8050,0.9350;0.5000), (0.32820.4589,0.9704,1.3049;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_{32}	[(0.3219,0.3826,0.5764,0.6755;0.5000), (0.2137,0.3085,0.7019,0.9555;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760;1.0000)]
C_{33}	[(0.7457,0.8470,0.9674,1.0713;0.5000), (0.6417,0.7848,1.04321.2304;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_{34}	[(0.1064,0.1457,0.2699,0.3452;0.5000), (0.0490,0.1037,0.3597,0.5743;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]

C_{41}	[(0.9614,0.99101.0000,1.0152;0.5000), (0.9450,0.9841,1.00801.0286;1.0000)]	[(0.9895,0.9970,0.9985,0.99850;0.5000), (0.9860,0.9960,1.0000,1.0000;1.0000)]
C_{42}	[(0.5711,0.6648,0.9134,1.0471;0.5000), (0.4287,0.5671,1.0780,1.4138;1.0000)]	[(0.7560,0.7865,0.8595,0.8840;0.5000), (0.6920,0.7500,0.8960,0.9480;1.0000)]
C_{43}	[(0.2341,0.3213,0.6363,0.8273;0.5000), (0.1157,0.2247,0.8874,1.5142;1.0000)]	[(0.5775,0.6130,0.6950,0.7245;0.5000), (0.5040,0.5720,0.7360,0.7980;1.0000)]
C_{51}	[(0.4640,0.5417,0.7527,0.8650;0.5000), (0.3339,0.4551,0.8850,1.1500;1.0000)]	[(0.5510,0.5845,0.6695,0.7010;0.5000), (0.4760,0.5420,0.7120,0.7760;1.0000)]
C_{52}	[(0.6701,0.7597,0.8919,0.9985;0.5000), (0.5635,0.6936,0.9731,1.1678;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]

Table 2.37: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 1nd level indices **(Alternative A_3)**

1nd Level indices	Computed fuzzy appropriateness rating, U_{ij}	Aggregated fuzzy priority weight, w_{ij}
C_1	[(0.6190,0.7493,1.0823,1.2887;0.5000), (0.4494,0.6257,1.3238,1.8556;1.0000)]	[(0.8260,0.8520,0.9080,0.9260;0.5000), (0.7760,0.8240,0.9360,0.9760,1.0000)]
C_2	[(0.6563,0.7069,0.9678,1.0735;0.5000), (0.4552,0.6315,1.1956,1.7021;1.0000)]	[(0.9145,0.9510,0.9710,0.9755;0.5000), (0.8880,0.9400,0.9840,0.9940;1.0000)]
C_3	[(0.3758,0.4666,0.7068,0.8618;0.5000), (0.2569,0.3796,0.8819,1.2942;1.0000)]	[(0.7295,0.7580,0.8340,0.8605;0.5000), (0.6640,0.7200,0.8720,0.9260;1.0000)]
C_4	[(0.5824,0.6690,0.9288,1.0929;0.5000), (0.4686,0.5828,1.1333,1.6394;1.0000)]	[(0.9025,0.9230,0.9525,0.9615;0.5000), (0.8740,0.9080,0.9680,0.9880;1.0000)]
C_5	[(0.5180,0.6334,0.8922,1.0784;0.5000), (0.3725,0.5298,1.0713,1.5052;1.0000)]	[(0.60400.6415,0.7205,0.7480;0.5000), (0.5320,0.6020,0.7600,0.8200;1.0000)]

Table 2.38: Normalized Weighted Decision-making Matrix

		Normalized Weighted Decision-making Matrix
C_1	A_1	[(0.0967,0.1217,0.1944,0.2383;0.5000), (0.0633,0.0961,0.2485,0.3691;1.0000)]
	A_2	[(0.0618,0.0798,0.1391,0.1752;0.5000, (0.0366,0.0600,0.1843,0.2894;1.0000)]
	A_3	[(0.1062,0.1285,0.1856,0.2210;0.5000), (0.0771,0.10730.2270,0.3183;1.0000)]
C_2	A_1	[(0.1068,0.1247,0.1838,0.2087;0.5000), (0.0666,0.1081,0.2371,0.3479;1.0000)]
	A_2	[(0.1133,0.1229,0.1743,0.1963;0.5000), (0.0749,0.1083,0.2197,0.3213;1.0000)]
	A_3	[(0.1295,0.1395,0.1910,0.2119;0.5000), (0.0898,0.1247,0.2360,0.3360;1.0000)]
C_3	A_1	[(0.0655,0.0852,0.1570,0.2009;0.5000), (0.0366,0.0621,0.2125,0.3431;1.0000)]
	A_2	[(0.0741,0.0980,0.1770,0.2247;0.5000), (0.0416,0.0721,0.2377,0.3789;1.0000)]
	A_3	[(0.0711,0.0917,0.1529,0.1923;0.5000), (0.0442,0.0709,0.1994,0.3108;1.0000)]
C_4	A_1	[(0.0829,0.1040,0.1729,0.2148;0.5000), (0.0538,0.0815,0.2273,0.3612;1.0000)]
	A_2	[(0.0710,0.0916,0.1580,0.1987;0.5000), (0.0434,0.0701,0.2108,0.3423;1.0000)]
	A_3	[(0.1274,0.1496,0.2144,0.2547;0.5000), (0.0993,0.1283,0.2659,0.3926;1.0000)]
C_5	A_1	[(0.0573,0.0769,0.1282,0.1630;0.5000), (0.0335,0.0585,0.1656,0.2585;1.0000)]
	A_2	[(0.0752,0.0977,0.1535,0.1921;0.5000), (0.0479,0.0770,0.1939,0.2930;1.0000)]
	A_3	[(0.0749,0.0973,0.1539,0.1931;0.5000), (0.0474,0.0764,0.1949,0.2955;1.0000)]

Table 2.39: Computed ratio system

Alternatives	RS_i	$d_{\tilde{\tilde{A}}}$	Ranking order
A_1	[(3.9765,4.1255,4.3860,4.4715;0.5000), (3.7340,3.9940,4.5200,4.7040;1.0000)]	4.711198	1
A_2	[(3.9765,4.0890,4.3295,4.4105;0.5000), (3.7605,3.9685,4.4505,4.6245;1.0000)]	4.648712	2
A_3	[(3.9765,4.0630,4.2475,4.3105;0.5000), (3.8105,3.9705,4.3405,4.4745;1.0000)]	4.593585	3

Table 2.40: Computed by reference point

Alternatives	$Max_j\{d(\beta_{ij},\beta_j)$	Ranking order
A_1	0.90890	3
A_2	0.90022	2
A_3	0.89077	1

Table 2.41: Computed by (Full-Multiplicative Form)

Alternatives	y_i	$d_{\tilde{\tilde{A}}}$	Ranking order
A_1	[(0.0000032,0.0000103,0.0001243,0.0003496;0.5000000), (0.0000003,0.0000031,0.0004712,0.0041122;1.0000000)]	1.6391	2
A_2	[(0.0000028,0.0000086,0.0001041,0.0002948;0.5000000), (0.0000002,0.0000025,0.0003933,0.0035346;1.0000000)]	1.6370	3
A_3	[(0.0000093,0.0000239,0.0001789,0.0004431;0.5000000), (0.0000014,0.0000093,0.0005538,0.0038548;1.0000000)]	1.6599	1

Table 2.42: Ranking of the Supply Chain Performance according to Dominance Theory

Alternatives	Ratio system approach	Reference point approach	Full multiplicative form	MULTIMOORA (final ranking order obtained by dominance theory)
A_1	1	3	2	**3**
A_2	2	2	3	**2**
A_3	3	1	1	**1**

CHAPTER 3

PERFORMANCE BENCHMARKING OF GREEN SUPPLY CHAIN

3.1 Green Supply Chain (GSC) Performance Benchmarking using Integrated IVFN-TOPSIS Methodology

3.1.1 Coverage

In today's era of globalization, manufacturing sectors are being forced towards managing environmental sustainability in account of leverage of numerous serious global warming issues. A multiple index based Green Supply Chain (GSC) performance appraisement framework has been conceptualized here from the resource literature survey to empirically investigate several sustainability issues related to environmental performance of candidate alternative industries. In this work, the subjectivity of the evaluation information has been taken into consideration by deploying a hierarchical fuzzy based computation module capable of dealing with uncertain evaluation information. Due to inherent ambiguity, vagueness, impreciseness and inconsistency associated with subjective information of the GSC performance indices (metric and measures); the assessment of expert panel acquired in linguistic terms pointed out by the adaptation of Interval-Valued Fuzzy Number (IVFN) set theory. Therefore, a new Interval-Valued Fuzzy Number in conjunction with modified TOPSIS (IVFM-TOPSIS) method has been explored at the deployed (hierarchical) framework for appraisement and benchmarking of the candidate industries operating under similar GSC hierarchy. Finally, an empirical study has led in order to exhibit the feasibility as well as effectiveness of the proposed methodology.

3.1.2 Problem Formulation

In today's competitive edge, enterprises have started adapting green supply chain management philosophies by considering environmental issues into the traditional supply chain management with the unified objectives of creating the green worth, firms' green image and thereby satisfactory consumers' response. Performance evaluation of GSCM as well as performance benchmarking from green perceptive is a complex as well as complicated task in view of candidate alternative industries. In this work, a 2-level performance appraisement hierarchical framework consisting of multiple subjective (indices) has been developed with the help of extensive literature review.

The judgment of the expert panels (linguistic preferences) have been transformed into Interval-Valued Fuzzy Numbers (IVFNs). The concept of IVFNs in conjunction with modified TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*) methodology has been explored towards appraisement (and benchmarking) of the preferred alternative industries running under similar GSC initiatives. Finally, an empirical case study has been carried out to provide a better understanding of the proposed appraisement framework. The raking order of preferred alternative industries has been derived in accordance with ascending value of the 'collective index'. Higher value of 'collective index' reflects higher degree of performance extent.

3.1.3 TOPSIS

The TOPSIS method was first proposed by Hwang and Yoon (Hwang and Yoon, 1981). It is based on the concept of Positive Ideal Solution (PIS) as well as Negative Ideal Solution (Anti-Ideal Solution) (NIS). The PIS is a solution that minimizes the cost criteria and maximizes the benefit criteria; whereas, the NIS maximizes the cost criteria and minimizes the benefit criteria. The so-called benefit criteria are those whose maximum values are proffered; whilst, the cost criteria are those whose minimum values are desired. The best alternative is the one, which is placed at closest to the PIS and farthest distance from the NIS.

Suppose a MCDM problem has m alternatives $(A_1, \ldots\ldots\ldots\ldots A_m)$ and n decision criteria $(C_1, \ldots\ldots\ldots\ldots, C_n)$. Each alternative is evaluated with respect to n criteria. All the ratings assigned to the alternatives with respect to each criterion form a decision-matrix denoted by $X = (x_{ij})_{mn}$. Let $W = (w_{1,}\ w_{2,\ldots\ldots\ldots}, w_n)$ be the relative weight vector about the criteria, satisfying $\sum_{j=1}^{n} w_j = 1$. Then, the TOPSIS method is summarized as follows:

Step 1:

Normalize the decision matrix $X = (x_{ij})_{mn}$ using the following equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x^2{}_{ij}}}, \quad i = 1, 2, 3, \ldots\ldots m,, \quad j = 1, 2, 3, \ldots\ldots n \tag{3.1}$$

Here r_{ij} is the normalized criterion rating.

Step 2:

Calculate the weighted normalized decision matrix $v = (v_{ij})_{mn}$:

Here w_j is the relative weight of the j^{th} criterion or attribute, and $\sum_{j=1}^{n} w_j = 1$.

Step 3:

Determine the PIS and NIS by:

$$A^* = \{v_1^*, \ldots\ldots\ldots., v_n^*.\} = \left\{ (\max_i v_{ij} \left(j \in \Omega_b \right], (\min_i v_{ij} \left(j \in \Omega_c \right] \right\}_j \tag{3.2}$$

$$A^- = \{v_1^-, \ldots\ldots\ldots., v_n^-.\} = \left\{ (\min_i v_{ij} \left(j \in \Omega_b \right], (\max v_{ij} \left(j \in \Omega_c \right] \right\}_j \tag{3.3}$$

Here Ω_b and Ω_c are the sets of benefit criteria and cost criteria, respectively.

Step 4:

Calculate the Euclidean distances of each alternative from the PIS and the NIS, respectively

$$D^*_i = \sqrt{\sum_{j=1}^{n} (v_{ij} - v^*_{ij})^2}, \quad i = 1, 2, 3, \ldots\ldots.m \tag{3.4}$$

$$D^-_i = \sqrt{\sum_{j=1}^{n} (v_{ij} - v^*_{ij})^2}, \quad i = 1, 2, 3, \ldots\ldots.m \tag{3.5}$$

Step 5:

Calculate the relative closeness of each alternative with respect to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined by:

$$RC_i = \frac{D_i^-}{D_i^* + D_i^-}, \quad i = 1, 2, 3, \ldots\ldots.m \tag{3.6}$$

Step 6:

Rank the alternatives according to their relative closeness to the ideal solution. The bigger the RC_i, the better the alternative A_i is. The best alternative is the one which is having the greatest relative closeness to the ideal solution.

3.1.4 Fuzzy Set Theory

The fuzzy set theory was first introduced by (Zadeh, 1965) for dealing with problems in which a source of vagueness is present. It has been considered as a modeling language to approximate situations in which fuzzy phenomena and fuzzy criteria exist. In a universe of discourse X, a fuzzy subset A of X is a set defined by a membership function $f_A(x)$ representing a mapping which maps each element x in X to a real number in the closed interval [0, 1]. Here, the value of $f_A(x)$ for the fuzzy set A is called the membership value (or the grade of the membership) of x in X. The membership value represents the degree of x belonging to the fuzzy set A. The greater $f_A(x)$ the stronger is the grade of membership for X in A.

The linguistic value could be used for approximate reasoning within the framework of fuzzy set theory (Zadeh, 1975) for handling effectively the ambiguity involved in the evaluation data and the vague property of linguistic expression; and normal trapezoidal or triangular fuzzy numbers could be used to characterize the fuzzy values of quantitative data and linguistic terms used in approximate reasoning. The operations of fuzzy numbers can be understood using the extension principle (Tanaka, 1997).

Interval-Valued Fuzzy Numbers Sets (IVFNs)

According to (Gorzalczany, 1987) an IVFS defined on $(-\infty, +\infty)$ is given by:

$$A = \{(x, \mu_A{}^L(x), \mu_A{}^U(x)])\} \tag{3.7}$$

$$\mu_A{}^L, \mu_A{}^U : X \to [0,1] \quad \forall x \in X,\ \mu_A{}^L \le \mu_A{}^U$$

$$\mu_A\ (x = \mu_A{}^L(x), \mu_A{}^U(x)$$

$$A = \{(x, \mu_A\ (x))\},\quad x \in (-\infty, \infty)$$

Here $\mu_A{}^L$ the lower is limit of degree of membership and $\mu_A{}^U$ is the upper limit of the membership degree.

Given two interval-valued fuzzy numbers $N_x = [N_x{}^-, N_x{}^+]$ and $M_x = [M_x{}^-, M_x{}^+]$, according to [10, 29], we have:

Definition 1:

If $\in (+,\, x)$ then $N\,.\,M(x,y) = [N_x^{-}.\ M_x^{-}, N_x^{+}\ \ .M_x^{+}]$ for a positive non-fuzzy number $(v), v\,.\ M(x,y) = [v.\ M_y^{-}, N_x^{+}\ \ .v\,.\,M_x^{+}]$.

Definition 2:

The subtraction and division operations between two triangular interval-valued fuzzy numbers $\tilde{N}$ and $\tilde{M}$ are as follows (Kuo, 2011):

$$\tilde{N} - \tilde{M} = [N_1, N'_1); N_2; (N'_3, N_3)] - [M_1, M'_1); M_2; (M'_3, M_3)]$$

$$[N_1 - M_3, N'_1 - M'_3); N_2 - M_2; (N'_3 - M'_1, N_3 - M_1)]$$

and

$$\tilde{N} \div \tilde{M} = [N_1, N'_1); N_2; (N'_3, N_3)] \div [M_1, M'_1); M_2; (M'_3, M_3)]$$
$$[N_1 \div M_3, N'_1 \div M'_3); N_2 \div M_2; (N'_3 \div M'_1, N_3 \div M_1)]$$

Definition 3:

The intersection of two IVFSs (Gorzalczany, 1987) is defined as the minimum of their respective lower and upper bounds of their membership intervals. Given two intervals of $[0,1]$ an $N_x = [N_x^{-}; N_x^{+}] \subset [0,1], M_y = [M_y^{-}; M_y^{+}] \subset [0,1]$, the minimum of both intervals is an Interval $K = Min(N_x, M_y) = [Min(N_x^{-}; M_y^{-}), Min(N_x^{+}; M_y^{+})]$.

Definition 4:

The union of two IVFSs (Mousavi et al., 2012) is defined as the maximum of their respective lower and upper bounds of their membership intervals. Given two intervals of $[0,1]$ and $N_x = [N_x^{-}; N_x^{+}] \subset [0,1], M_y = [M_y^{-}; M_y^{+}] \subset [0,1]$, the maximum of both intervals is $K = Max(N_x, M_y) = [Max(N_x^{-}; M_y^{-}), Max(N_x^{+}; M_y^{+})]$.

Definition 5: Absolute value: $|N_x| = Max\{|N_x^{-}|, |N_x^{+}|\}$.

Definition 6:

Let $\tilde{N}$ and $\tilde{M}$ be two triangular interval-valued fuzzy numbers $\tilde{N}=[N_1, N'_1); N_2; (N'_3, N_3)]$ and $\tilde{N}=[M_1, M'_1); M_2; (M'_3, M_3)]$ can then be represented as follows:

$$h(\tilde{N})=\frac{N_1+N'_1+N_2+N'_3+N_3}{6}, \tag{3.8}$$

and

$$h(\tilde{N})=\frac{M_1+M'_1+N_2+M'_3+N_3}{6}, \tag{3.9}$$

We say $\tilde{N}$ > M′ if h($\tilde{N}$) > h(M′).

3.1.5 Interval-Valued Fuzzy Modified TOPSIS Method

A Multi-Criteria Decision Making (MCDM) problem can be concisely articulated in a decision matrix, whose component indicates the evaluation or a value of an alternative with respect to a criterion. This work develops the decision matrix format to the interval-valued fuzzy decision matrix; that is, the Decision-Makers (DMs) are expected to assign an extent of membership grades that capture the degree of the alternative satisfying the criterion according to their judgments. In some cases, determining precisely of this evaluation is difficult, and the membership value can be expressed as an interval consisting of real numbers. Zadeh (1975) introduced the concept of the linguistic variable which is fruitful in dealing with these situations that are too complex or ill-defined to be reasonably described in conventional quantitative expressions and then convert into related fuzzy numbers.

Modeling a phenomenon in the traditional linguistic approach is not clear enough because of its presentation in the form of ordinary fuzzy sets (Cornelis et al.; 2006; Grzegorzewski, 2004). thus, it is more appropriate to represent this degree of certainty by an interval form. In addition, in the fuzzy sets theory, it is often difficult for an expert to exactly quantify his or her opinion as a number in interval $[0,1]$. For this purpose, this work considers the performance rating and criteria weights as linguistic variables and then transforms into Interval-Valued Fuzzy Numbers (IVFNs), which are the generalization of ordinary fuzzy sets.

Let $\tilde{X}=[x_{ij}]_{m\times n}$ be a fuzzy decision matrix for the MCDM problem, in which $(A_1, A_2 .... A_m)$ are m possible alternatives and $(C_1, C_2 ...., C_n)$ are n criteria.

Therefore, the performance of alternative A_i with respect to criterion C_i is denoted a $\tilde{x}_{ij}$. As illustrated in Fig. 3.1, $\tilde{x}_{ij}$ and $\tilde{w}_j$ are expressed in triangular Interval-Valued Fuzzy Numbers (TIVFNs).

$$\begin{cases}(x_1, x_2, x_3)\\(x'_1, x'_2, x'_3)\end{cases}$$

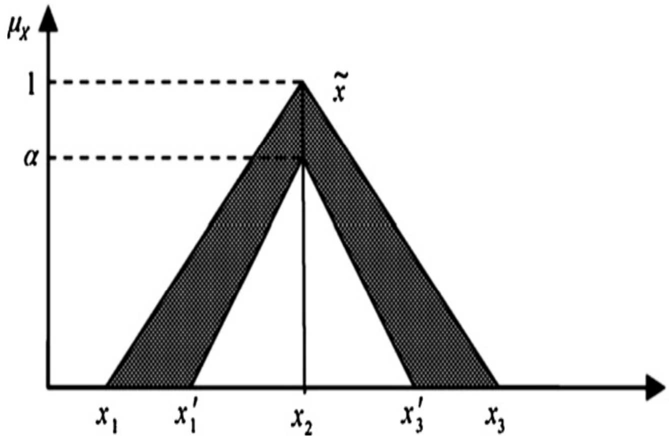

Fig. 3.1: Triangular Interval-Valued Fuzzy Number (TIVFN) (Vahdani et al., 2013)

The $\tilde{x}$ can be also expressed as $\tilde{x} = [x_1, x'_1); x_2; (x'_3, x_3)]$. It is worth noting that the use of TIVNFs gives an opportunity to experts or (DMs) to define lower and upper bounds values as an interval for matrix's elements and weights of criteria. In addition to this, in a group decision environment with K persons, the importance of the criteria and the rating of alternatives with respect to each criterion can be computed by:

$$\tilde{x}_{ij} = \frac{1}{k}[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + ... + \tilde{x}_{ij}^k] \tag{3.10}$$

$$\tilde{w}_{ij} = \frac{1}{k}[\tilde{w}_{ij}^1 + \tilde{w}_{ij}^2 + ... + \tilde{w}_{ij}^k] \tag{3.11}$$

Eq. 3.10 and 3.11 represent the average values of $\tilde{x}_{ij}$ and $\tilde{w}_{ij}$ denoted by experts, where $(+)$ is the 'sum operator' and is applied to the Interval-Valued Fuzzy Numbers as defined in Definition 1. So, the output is an interval-valued fuzzy number. Now, the proposed VIFM-TOPSIS method can be presented as follows:

Step 1:

Given $\tilde{x}_{ij} = [a_{ij}, a'_{ij}); b_{ij}; (c'_{ij}, c_{ij})]$. The normalized performance rating can be calculated by:

$$\tilde{n}_{ij} = \left[(\frac{a_{ij}}{c_j^+}, \frac{a'_{ij}}{c_j^+}); \frac{b_{ij}}{c_j^+}; (\frac{c'_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}) \right], \quad i = 1,........., n, \quad j \in \Omega_b \tag{3.12}$$

$$\tilde{n}_{ij} = \left[(\frac{a_j^-}{c'_{ij}}, \frac{a_j^-}{c_{ij}}); \frac{a_j^-}{b_{ij}}; (\frac{a_j^-}{a'_{ij}}, \frac{a_j^-}{a_{ij}}) \right], \quad i = 1,........., n, \quad j \in \Omega_c \tag{3.13}$$

$$c_j^+ = \underset{i}{Max} c_{ij}, \quad j \in \Omega_b$$

$$a_j^- = \underset{i}{Min} a_{ij}, \quad j \in \Omega_c$$

Here Ω_b and Ω_c are associated with benefit and cost criteria, respectively. Hence, the normalized matrix $\tilde{N} = (n_{ij})_{n \times m}$ can be obtained. The above-mentioned normalization method is to preserve the property that the ranges of normalized interval numbers fall within the interval $[0,1]$.

Step 2:

Determine the weighted normalized matrix. By considering the different importance of each criterion, we can construct the weighted normalized fuzzy decision matrix as:

$$\tilde{V} = [v_{ij}]_{n \times m} \tag{3.14}$$

Here,

$$\tilde{v}_{ij} = \tilde{w}_{ij} \times n_{ij}. \tag{3.15}$$

According to Definition 1, the 'multiplication operator' can be applied as:

$$\tilde{v}_{ij} = [[(\tilde{w}_{1j} \times n_{1\,ij}\, \tilde{w}_{1j} \times n'_{1\,ij}); \tilde{w}_{2j} \times n_{2\,ij}; (\tilde{w}_{3j} \times n_{3\,ij}\, \tilde{w}_{3j} \times n'_{3\,ij})]] \tag{3.16}$$

Step 3:

Determine the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). The values for A^* and A^- are defined as follows with respect to Eq. 3.17 or Eq. 3.18.

$$A^- = \{v_1^*, ..., v_n^*.\} = \left\{ (\underset{i}{\max} v_{ij} \left(j \in \Omega_b \right], (\min v_{ij} \left(j \in \Omega_c \right] \right\}_j \tag{3.17}$$

$$A^{-}=\{v_1^{-},.........,v_n^{-}.\}=\left\{(\min_i v_{ij}\left(j\in\Omega_b\right],(\max_j v_{ij}\left(j\in\Omega_c\right]\right\} \tag{3.18}$$

Here, Ω_b and Ω_c are the sets of benefit criteria and cost criteria. Obviously, A^* indicates the most preferable alternative or the PIS. Similarly, A^{-} indicates the least preferable alternative or the NIS.

Step 4:

Construct ideal separation matrix (D^*) and anti-ideal separation matrix D^* which are defined as follows:

$$D^*=\left[d_{ij}^*\right]=\begin{bmatrix} \left|\tilde{v}_{11}-\tilde{v}_1^*\right| & \left|\tilde{v}_{12}-\tilde{v}_2^*\right| & \left|\tilde{v}_{13}-\tilde{v}_3^*\right| & \left|\tilde{v}_{1n}-\tilde{v}_n^*\right| \\ \left|\tilde{v}_{22}-\tilde{v}_2^*\right| & \left|\tilde{v}_{22}-\tilde{v}_2^*\right| & \left|\tilde{v}_{33}-\tilde{v}_3^*\right| & \left|\tilde{v}_{2n}-\tilde{v}_n^*\right| \\ & & & \\ \left|\tilde{v}_{m1}-\tilde{v}_1^*\right| & \left|\tilde{v}_{m2}-\tilde{v}_2^*\right| & \left|\tilde{v}_{m3}-\tilde{v}_3^*\right| & \left|\tilde{v}_{mn}-\tilde{v}_n^*\right| \end{bmatrix} \tag{3.19}$$

According to Definition 2, the 'subtraction operator' can be applied as:

$$D^*=\left[d_{ij}^*\right]=\begin{bmatrix} [(v_{1(1,1)},v'_{1(1,1)});v_{2(1,1)};(v'_{3(1,1)},v_{3(1,1)})]-[(v^*_{1(1)},v^*_{1(1)});v^*_{2(1)};(v^*_{3(1)},v^*_{3(1)})]\ldots\ldots\ldots\ldots\ldots \\ [(v_{1(1,n)},v'_{1(1,n)});v_{2(1,n)};(v'_{3(1,n)},v_{3(1,n)})]-[(v^*_{1(n)},v^*_{1(n)});v^*_{2(n)};(v^*_{3(n)},v^*_{3(n)})] \\ .. \\ \ldots \\ [(v_{1(m,1)},v'_{1(m,1)});v_{2(m,1)};(v'_{3(m,1)},v_{3(m,1)})]-[(v^*_{1(1)},v^*_{1(1)});v^*_{2(1)};(v^*_{3(1)},v^*_{3(1)})]\ldots\ldots\ldots\ldots\ldots \\ [(v_{1(m,n)},v'_{1(m,n)});v_{2(m,n)};(v'_{3(m,n)},v_{3(m,n)})]-[(v^*_{1(n)},v^*_{1(n)});v^*_{2(n)};(v^*_{3(n)},v^*_{3(n)})] \end{bmatrix} \tag{3.20}$$

$$D^{-}=\left[d_{ij}^{-}\right]=\begin{bmatrix} \left|\tilde{v}_{11}-\tilde{v}_1^{-}\right| & \left|\tilde{v}_{12}-\tilde{v}_2^{-}\right| & \left|\tilde{v}_{13}-\tilde{v}_3^{-}\right| & \left|\tilde{v}_{1n}-\tilde{v}_n^{-}\right| \\ \left|\tilde{v}_{22}-\tilde{v}_2^{-}\right| & \left|\tilde{v}_{22}-\tilde{v}_2^{-}\right| & \left|\tilde{v}_{33}-\tilde{v}_3^{-}\right| & \left|\tilde{v}_{2n}-\tilde{v}_n^{-}\right| \\ . & . & . & . \\ \left|\tilde{v}_{m1}-\tilde{v}_1^{-}\right| & \left|\tilde{v}_{m2}-\tilde{v}_2^{-}\right| & \left|\tilde{v}_{m3}-\tilde{v}_3^{-}\right| & \left|\tilde{v}_{mn}-\tilde{v}_n^{-}\right| \end{bmatrix} \tag{3.21}$$

According to Definition 2, the 'subtraction operator' can be applied as:

$$D^{-}=\left[d_{ij}^{-}\right]=\begin{bmatrix} [(v_{1(1,1)},v'_{1(1,1)});v_{2(1,1)};(v'_{3(1,1)},v_{3(1,1)})]-[(v^{-}_{1(1)},v^{-}_{1(1)});v^{-}_{2(1)};(v^{-}_{3(1)},v^{-}_{3(1)})]\ldots\ldots\ldots\ldots\ldots\ldots \\ [(v_{1(1,n)},v'_{1(1,n)});v_{2(1,n)};(v'_{3(1,n)},v_{3(1,n)})]-[(v^{-}_{1(n)},v^{-}_{1(n)});v^{-}_{2(n)};(v^{-}_{3(n)},v^{-}_{3(n)})] \\ .. \\ .. \\ [(v_{1(m,1)},v'_{1(m,1)});v_{2(m,1)};(v'_{3(m,1)},v_{3(m,1)})]-[(v^{-}_{1(1)},v^{-}_{1(1)});v^{-}_{2(1)};(v^{-}_{3(1)},v^{-}_{3(1)})]\ldots\ldots\ldots\ldots\ldots \\ [(v_{1(m,n)},v'_{1(m,n)});v_{2(m,n)};(v'_{3(m,n)},v_{3(m,n)})]-[(v^{-}_{1(n)},v^{-}_{1(n)});v^{-}_{2(n)};(v^{-}_{3(n)},v^{-}_{3(n)})] \end{bmatrix} \tag{3.22}$$

With respect to Definition 5, ideal separation matrix (D^{*}) and anti-ideal separation matrix (D^{-}) are converted into a matrix with absolute numbers which are presented as follows:

$$D^{*}=\begin{bmatrix} d_{11}^{*} & d_{12}^{*} & \ldots\ldots & d_{1n}^{*} \\ d_{21}^{*} & d_{22}^{*} & \ldots\ldots. & d_{2n}^{*} \\ : & : & : & : \\ d_{m1}^{*} & d_{m2}^{*} & \ldots\ldots.. & d_{mn}^{*} \end{bmatrix}, \tag{3.23}$$

and

$$D^{-}=\begin{bmatrix} d_{11}^{-} & d_{12}^{-} & \ldots\ldots & d_{1n}^{-} \\ d_{21}^{-} & d_{22}^{-} & \ldots\ldots. & d_{2n}^{-} \\ : & : & : & : \\ d_{m1}^{-} & d_{m2}^{-} & \ldots\ldots.. & d_{mn}^{-} \end{bmatrix}, \tag{3.24}$$

Step 5:

Calculate collective index (CI). This index is calculated by:

$$\Gamma_{i}(D^{*},D^{-})=\left(\sum_{l=1(A)}^{L}\frac{d_{ij}^{*}}{d_{ij}^{-}}\right)^{1/L}+z_{ij'}, \qquad \forall_{i}=1,2\ldots\ldots\ldots\ldots,m. \tag{3.25}$$

Here, the first summation (ΣA) refers to all j for which $d_{ij}^{-}>0$ while $(z_{ij'})$ refers to all j for which $d_{ij}^{-}=0$. Further, $z_{ij'}$ can be calculated such that $z_{ij'}=((\max_{j'}(d_{ij}^{*}/d_{ij}^{-})))^{1/\max_{j} w_{j}}$ for which $d_{ij}^{-}>0$ and w_{j} for $d_{ij}^{-}=0$.

$$\varsigma_i\ (D^*, D^-) = \left(\sum_{l=1}^{L} d_{ij}^*\right)^{1/m} + \left(\sum_{l=1(A)}^{L} \frac{1}{d_{ij}^-}\right)^{1/L} + Q_{ij'}, \qquad \forall_i = 1,2,..........m. \tag{3.26}$$

Here, the second summation (ΣA) refers to all j for which $d_{ij}^- > 0$ while $(Q_{ij'})$ refers to all j for which $d_{ij}^- = 0$. Further, $Q_{ij'}$ can be calculated such that $Q_{ij'} = ((\min_{j'}(d_{ij'}^-)))^{1/\max_j w_j}$ for which $d_{ij}^- > 0$ and w_j for $d_{ij}^- = 0$.

Finally, the collective index is calculated as follows:

$$CI_i = \Gamma_i + \varsigma_i \tag{3.27}$$

Step 6:

Rank the preference order. The best satisfied alternative can be decided according to the preference ranking order of Γ_i and ς_i. The minimum value of the collective index indicates better performance for alternative A_i.

According to the Interval-Valued Fuzzy decision matrix, the new MCDM method has been presented that might reflect both subjective judgments and objective information in real life situations. The proposed VIFM-TOPSIS method is based on concepts of the PIS and the NIS for solving decision-making problems by considering multiple judges and multiple criteria in an uncertain environment. It is a generalized form of the ordinary fuzzy sets by using the Triangular Interval-Valued Fuzzy Numbers (TIVFNs). The presented method provides with a useful way to deal with fuzzy MCDM problems in a more flexible and intelligent manner due to the fact that it utilizes IVFNs set rather than ordinary fuzzy sets to represent the alternative rating with respect to criteria and the weights of criteria. Moreover, the new relative closeness (i.e., CI) is presented by considering two indices in order to discriminate successfully and clearly amongst alternatives in the ranking process along with its simplicity and flexibility in respect to subjective or objective criteria.

The usefulness of the aforesaid approach has been summarized below (Vahdani et al., 2013).

1. A new version of fuzzy sets in Interval-Valued (IV) form has been adapted, which provides more flexibility and better representation uncertainties than traditional fuzzy sets because of the fact that triangular Interval-Valued fuzzy numbers have been utilized.
2. A new relative closeness (i.e., CI) based on two indices has been computed that considers the relative distance of alternatives from the reference points effectively.

3. In the said IVFM-TOPSIS method for each criterion, the alternatives rating and the criteria weights can be expressed with linguistic variables and then transformed into a generalized form of ordinary fuzzy sets.
4. The method constructs the ideal separation and anti-ideal separation matrix based on the operations between Triangular Interval-Valued Fuzzy Numbers (TIVFNs) to distinguish among the alternatives in the decision-making problem better than the previous studies based on Euclidean distances of each alternative from the PIS and the NIS.
5. The effect of weights of criteria, which can be highly important in the ranking process of alternatives in MCDM problems, is clearly regarded by using new indices in the evaluations rather than the previous studies.
6. The IVFN-TOPSIS method can deal with the situations, in which fuzzy and non-fuzzy evaluations are required. In fact, the aforesaid method assists the experts or DMs to take data in the form of linguistic terms, Triangular Interval-Valued Fuzzy Numbers (TIVFNs), and/or crisp numbers in MCDM problems. This leads to more realistic and reliable decision-making process than the existing ones.

3.1.6 Empirical Research: Data Analyses

The green supply chain performance evaluation index platform [Source: Huiyu and Weiwei, 2010; Min and Galle, 1997; Zhu et al., 2008; Hsieh, 2011; Xu et al., 2013; Lin et al., 2011; Shen et al., 2013; Toke et al., 2012; Azevedo et al., 2011; Dharmadhikari, 2012] developed in this work has been shown in (Table 3.1). Assume that there are three alternative industries correspond to similar green supply chain architecture. The unified aim of this study is to select the best one with respect to the 'green performance'. The 2-level hierarchical evaluation platform consists of various green initiatives /indices (measures and metrics) (Table 3.1). Green purchasing (C_1), Green marketing (C_2), Green production (C_3), Green design (C_4), Green packaging (C_5), Green recycling (C_6) have been considered as the 1st level indices (called measures) followed by 2nd level metrics. A modified TOPSIS methodology embedded with Triangular Interval-Valued Fuzzy Numbers Set (TIVFNS) proposed by (Vahdani et al., 2013), has been adapted here in order to evaluate an appropriate ranking order of alternative industries in perspective of green supply chain performance. This method has been found fruitful as it is capable of effectively and efficiently dealing with fuzzy MCDM problems in a more flexible as well as intelligent way due to its ability to cope up with the uncertainty and vagueness in the assessed subjective information by expert panel members.

Empirical research has been carried out to verify application credentials of said approach towards finding the best alternative under fuzzy environment. Assume that a committee of five decision-makers (expert group) such as $(DM_1, DM_2, DM_3, DM_4, DM_5)$ has been constructed consisting of members like management consultant/practitioner as well as academician. Also, assume that there are three alternative industries such as A_1, A_2, A_3, running under similar GSC architecture. It can also be said that they have been pursuing similar type of 'green initiatives'.

Based on several brainstorming session and periodical discussion, the decision-making group first finalizes important measures and metrics to be considered towards assessing green supply chain performance extent for the candidate industries. Following which, the expert group must assign priority weight against individual performance measures or metrics. Now, the decision-making group needs to visit candidate industries and monitor ongoing green performance. Based on that, the group members (or DMs) must provide their judgment (evaluation information) regarding performance extent of each elements/entities (indices) of the GSC hierarchy.

In this work, priority weights against individual performance indices/initiatives and corresponding performance extent (appropriateness ratings) have been obtained by linguistic information, provided by the expert group; which have been further transformed into TIVFNs. Here, these linguistic variables for rating as well as weight assignment of various performance measures-metrics (from 1st to 2nd level of the evaluation hierarchy) has been expressed in fuzzy numbers by 1-7 scale as pointed out in Table 3.2 and 3.3, respectively. The procedural steps of the proposed performance appraisement and benchmarking followed by results of empirical data analysis have been summarized as follows:

Step 1: Collection of expert judgment (in linguistic terms) on account of priority weight and appropriateness rating of individual evaluation indices.

A committee of fives decision-makers: $DM_1, DM_2, DM_3, DM_4, DM_5$ has been constructed. The team members have been instructed to express their subjective preferences (valuation score) in linguistic terms for determining criteria weights from 2nd to 1st level, as well as appropriateness rating only for 2nd level green supply chain metrics/ initiatives pointed out in Tables 3.1. Linguistic preferences have been transformed into Interval-Valued (IV) triangular fuzzy number in accordance with the scale chosen (Table 3.2-3.3). The linguistic data on assessing importance weights of various supply chain indices as given by the decision-makers (DMs) have been shown in (Tables 3.4-3.5), for 2nd and 1st level indices, respectively. The appropriateness rating (in linguistic terms) against individual 2nd level evaluation indices as assigned by the DMs have been furnished in (Tables 3.6-3.8), for alternative A_1, A_2 and A_3, respectively.

Step 2: Approximation of linguistic evaluation information using Interval-Valued (IV) triangular fuzzy numbers

Using the concept of Interval-Valued Fuzzy Numbers (IVFNs) in fuzzy set theory, the linguistic variables have been transformed into corresponding appropriate fuzzy rating as well weight indicator scale as shown in (Table 3.2-3.3). Next, based on simple fuzzy average rule; aggregated performance ratings of various 2nd level indices have been computed; shown in Table 3.9. Similarly, the aggregated fuzzy priority weights for 2nd level evaluation indices have been computed (which is common for every alternative); and shown in Table 3.10. Following the backward path (starting from 2nd level towards 1st level of the evaluation hierarchy: Table 3.1) and exploring fuzzy weighted average rule; performance ratings of different evaluation indices at the 1st level (immediate predecessor of 2nd level) have been computed.

Appropriateness rating for each of the 1st level evaluation index U_i (rating of i_{th} index) has been computed as follows (Lin et al., 2006):

$$FPI = U_i = \frac{\Sigma U_{ij} \otimes w_{ij}}{\Sigma w_{ij}} \tag{3.28}$$

In this expression (Eq. 3.28) U_{ij} is denoted as aggregated appropriateness rating and aggregated fuzzy weights obtained (from Eqs. 3.10-3.11) against j_{th} index (at 2nd level) which is under i_{th} index in the 1st level. Also w_{ij} is the aggregated fuzzy weight against j_{th} index (at 2nd level) which is under i_{th} index at 1st level.

Thus, the situation appears towards solving a feasible solution from the decision-making matrix, involving a number of alternatives candidate industries corresponding to a set of evaluation criteria.

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & C_2 & C_4 & C_5 \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} \end{bmatrix} \end{array}$$

Step 3: Normalization

All of the indices/metric have been assumed benefit in nature and expressed in terms of Interval-Valued (IV) triangular fuzzy numbers but ranges of normalized interval numbers fall within the interval $[0,1]$. Therefore, normalization has been led by exploring Eq. 3.12.

Step 4: Construction of Weighted Normalized Decision Matrix

The weighted normalized Interval-Valued (IV) fuzzy decision matrix has been found out in consideration with different importance of each performance indices assessed by decision-makers; now the weighted normalized fuzzy decision matrix has been constructed by exploring (Eqs. 3.15-3.16), and the normalized weighted matrix has been furnished in Table 3.11.

Step 5: Determination of Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

All of the performance indices have been assumed beneficial in nature and computation of positive ideal A^* and negative ideal solutions A^- has been carried out by using (Eq. 3.17). Results have been shown in Table 3.12.

Step 6: Ideal Separation Matrix (D*) and Anti-Ideal Separation Matrix (D−)

The ideal separation matrix (d*) and the anti-ideal separation matrix (d−) with the help of (Eqs. 3.19-3.21) and absolute value from (definition 5) to convert the matrix into a scrip value matrix as shown in Table 3.13.

Step 7: Computation of Values Γ_i , ς_i and CI_i

The values of Γ_i, ς_i and CI_i have been computed using Eqs. 3.25-3.27, and presented in Table 3.14 and Fig. 3.2.

Step 7: Determination of the Final Ranking Order of Alternative Industries

Finally, ranking order has been derived in accordance to ascending value of collective index. Result shows that second alternative (A_2) should be best choice as per the judgment of decision-makers; whereas, the first alternative (A_1) is the second-best choice. At the other end of spectrum, third alternative A_3 is the worst choice in view of GSC performance extent.

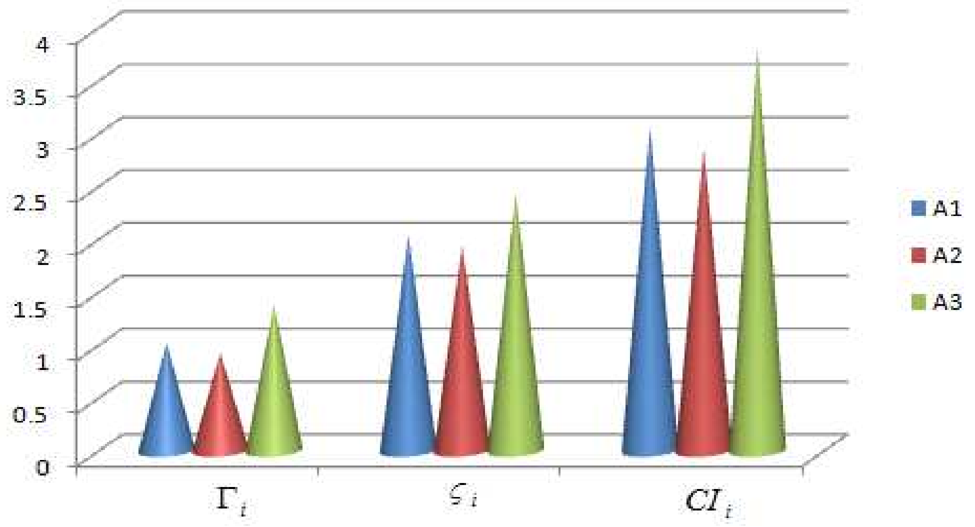

Fig. 3.2: Cone chart analysis for computed values of Γ_i, ς_i and CI_i

3.1.7 Managerial Implication

In today's scenario, green supply chain performance measurement (GSCPM) has received tremendous attention from the society of industrialists to overcome environmental barriers such global warming, acid rain, waste disposal etc. Therefore, the managers of enterprises are subjected to intention in mind towards greening their supply chain which could help them to prioritize better, manage their resources in an effective as well as economic way and even help them to successfully revitalize potential benefits of implementing green supply chain strategies into the traditional SC. From the prospect of evaluating and assessing the overall green supply chain performance extent of candidate enterprises, a hierarchical framework model has been developed here. In this work, subjectivity of appropriateness rating as well as priority weight against individual GSC performance evaluation criterions have been assessed by expert panels which have finally been tackled by effectively exploring Interval-Valued Fuzzy Numbers Set theory combined with modified TOPSIS methodology. This methodology has been found to be of quite efficient, simple and flexible of solving such a multi criteria decision making (MCDM) problem dealing with the subjective evaluation information in an efficient manner. The utility of this research is to pass through a message to the managers that how environmental performance measurements can be applied across managerial levels as well as company borders in a supply chain and how it may help them to evaluate, appraise and benchmark of preferred candidate alternative industries running under similar GSC initiatives. Performance benchmarking may help in selecting the best amongst possible alternatives; best practices of the top-ranked 'green' enterprise can be made transmitted to the other enterprises. Industries can follow their peers in order to boost up the level of green performance as desired.

3.1.8 Concluding Remarks

The main objective of this research has been to develop a conceptual hierarchical evaluation index platform for measuring environmental performance of green supply chains in perspective of alternative candidate industries operating under similar green initiatives (green supply chain). The contribution of this research has been the exploration of Interval-Valued Fuzzy Numbers (IVFNs) set theory in conjunction with modified TOPSIS philosophy towards appraisement and benchmarking of green SC performance. The case empirical study depicts fruitfulness of the said approach. This approach can also be applied to any MCDM problem which involves some sort of uncertainty as well as vagueness due to subjectivity of the evaluation criterions.

Table 3.1: Green Supply Chain Performance Appraisement Modeling
[Source: Min and Galle, 1997; Zhu et al., 2008; Hsieh, 2011; Xu et al., 2013; Lin et al., 2011; Shen et al., 2013; Toke et al., 2012; Azevedo, 2011; Dharmadhikari, 2012]

Goal (C)	Measures (1st level indices)	Metric (2nd level indices)
GSCM Performance Measurement	Green purchasing, C_1	Potential liability for disposal of hazardous materials, $C_{1,1}$
		Cost for disposal of hazardous materials, $C_{1,2}$
		Fulfillment of state environmental regulations, $C_{1,3}$
		Fulfillment of federal environmental regulations, $C_{1,4}$
		Cost of environmentally friendly goods, $C_{1,5}$
		Cost of environmentally friendly packages, $C_{1,6}$
		Buying firm's environmental mission, $C_{1,7}$
		Supplier's commitment in providing environmentally friendly packages, $C_{1,8}$
		Supplier's commitment in developing environmentally friendly goods, $C_{1,9}$
		Environmental partnership with suppliers, $C_{1,10}$
		Environmental audit for suppliers' internal management, $C_{1,11}$
		Suppliers' ISO14000 certification, $C_{1,12}$
		Evaluation of suppliers' environmental practices, $C_{1,13}$
	Green marketing, C_2	Green Service, $C_{2,1}$
		Green Advertisement, $C_{2,2}$
		Green Delivery, $C_{2,3}$
		Emotional Purchase, $C_{2,4}$
		Impulsive Purchase, $C_{2,5}$
		Routine Purchase, $C_{2,6}$
		Problem Recognition, $C_{2,7}$
		Information Search, $C_{2,8}$
		Alternative Evaluation, $C_{2,9}$
		Reducing risk of consumer criticism, $C_{2,10}$
		Expansion of product market to a global level, $C_{2,11}$
		Demand from customers, $C_{2,12}$
		Collaboration with customers, $C_{2,13}$
		Competitive advantage in adopting green strategies, $C_{2,14}$
		Green strategy of substitute product producers, $C_{2,15}$
		Export potential of the green product, $C_{2,16}$
		Establishing company's green image, $C_{2,17}$
		Anticipating improvement in product functional quality, $C_{2,18}$
	Green	Internal multinational policies leading to advantage over competitors, $C_{3,1}$

	Manufacturing /production, C_3	Anticipating synergy with care systems, risk reduction, increased efficiency in production, storage, distribution, $C_{3,2}$
		E-logistics and environment, $C_{3,3}$
		Skill policy entrepreneurs, $C_{3,4}$
		Extension of founder's value, $C_{3,5}$
		Integration with green product suppliers, $C_{3,6}$
		Scrap/ waste reduction, $C_{3,7}$
		Quality improvement, $C_{3,8}$
		Delivery improvement, $C_{3,9}$
		Capacity utilization, $C_{3,10}$
	Green design,C_4	Design of products for reduced consumption of material/energy, $C_{4,1}$
		Design of products for reuse, recycle, recovery of material, component parts, $C_{4,2}$
		Design of products to avoid or reduce use of hazardous products and/or their manufacturing process, $C_{4,3}$
		Certified requirement of environmental management system, $C_{4,4}$
		Public disclosure of environmental record, $C_{4,5}$
		Development of clean technologies, $C_{4,6}$
		Reduction in environmental emissions, $C_{4,7}$
	Green packaging, C_5	Integrating environmental thinking and innovation in packaging, $C_{5,1}$
		Utilization of packing material which is having minimum or no environmental impact, $C_{5,2}$
		Eco-labeling of products or packaging, $C_{5,3}$
		Use of recycled material in packaging, $C_{5,4}$
		Reduction in packaging weight, $C_{5,5}$
		Environment friendly disposal of packaging material, $C_{5,6}$
		Utilization of waste or scrap (of one product) as packaging material (for another product), $C_{5,7}$
	Green recycling, C_6	Effective recovery (collection) of virgin material from incoming mining material, $C_{6,1}$
		Recycling degree to ensure full usage of resources, $C_{6,2}$
		Recycling cost (transport and storage costs), $C_{6,3}$
		Recycling revenues, $C_{6,4}$
		Percentage of materials remanufactured, $C_{6,5}$
		Percentage of materials recycled or reused, $C_{6,6}$
		Returning product ratio, $C_{6,7}$

Table 3.2: Definitions of linguistic variables for the ratings

Linguistic variables	Triangular interval-valued fuzzy numbers
Very Poor (VP)	[(0,0); 0; (1,1.5)]
Poor (P)	[(0, 0.5); 1; (2.5, 3.5)]
Moderately Poor (MP)	[(0, 1.5); 3; (4.5, 5.5)]
Fair (F)	[(2.5, 3.5); 5; (6.5, 7.5)]
Moderately Good (MG)	[(4.5,5.5); 7; (8, 9.5)]
Good (G)	[(5.5, 7.5); 9; (9.5, 10)]
Very Good (VG)	[(8.5, 9.5); 10; (10, 10)]

Table 3.3: Definitions of linguistic variables for the importance of each criterion

Linguistic variables	Triangular interval-valued fuzzy numbers
Very Low (VL)	[(0,0); 0; (0.1, 0.15)]
Low (L)	[(0,0.05); 0.1; (0.25, 0.35)]
Medium Low (ML)	[(0,0.15);0.3;(0.45,0.55)]
Medium (M)	[(0.25,0.35); 0.5; (0.65,0.75)]
Medium High (MH)	[(0.45,0.55); 0.7; (0.8,0.95)]
High (H)	[(0.55,0.75); 0.9; (0.95,1.0)]
Very High (VH)	[(0.85,0.95); 1.0; (1.0, 1.0)]

Table 3.4: Priority weight against individual 2nd level indices as given by the DMs

2nd level indices, $C_{i,j}$	Linguistic judgment of the DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	H	H	H	H	H
$C_{1,2}$	H	VH	VH	H	H
$C_{1,3}$	H	MH	MH	MH	H
$C_{1,4}$	H	VH	H	VH	H
$C_{1,5}$	H	H	H	H	MH
$C_{1,6}$	M	MH	MH	MH	MH
$C_{1,7}$	MH	H	MH	H	MH
$C_{1,8}$	H	H	H	H	H
$C_{1,9}$	H	VH	VH	VH	H
$C_{1,10}$	H	VH	H	VH	H
$C_{1,11}$	H	H	H	H	H
$C_{1,12}$	H	H	VH	H	H
$C_{1,13}$	H	VH	VH	H	H
$C_{2,1}$	H	MH	H	MH	H
$C_{2,2}$	H	VH	H	VH	H
$C_{2,3}$	H	H	H	H	MH
$C_{2,4}$	M	MH	H	MH	MH
$C_{2,5}$	MH	H	VH	H	MH
$C_{2,6}$	H	H	H	H	H

$C_{2,7}$	H	VH	VH	VH	VH
$C_{2,8}$	H	VH	H	VH	H
$C_{2,9}$	H	H	H	H	H
$C_{2,10}$	H	H	H	H	H
$C_{2,11}$	H	VH	VH	VH	VH
$C_{2,12}$	H	H	VH	H	H
$C_{2,13}$	H	VH	VH	H	H
$C_{2,14}$	H	VH	H	MH	H
$C_{2,15}$	H	VH	H	VH	H
$C_{2,16}$	H	H	H	H	MH
$C_{2,17}$	M	MH	H	VH	MH
$C_{2,18}$	MH	H	VH	H	MH
$C_{3,1}$	H	H	H	H	H
$C_{3,2}$	H	VH	VH	VH	VH
$C_{3,3}$	H	VH	H	VH	VH
$C_{3,4}$	H	H	H	H	VH
$C_{3,5}$	H	H	VH	H	VH
$C_{3,6}$	H	VH	VH	H	H
$C_{3,7}$	H	MH	H	MH	H
$C_{3,8}$	H	VH	H	VH	VH
$C_{3,9}$	H	H	H	H	MH
$C_{3,10}$	M	MH	H	MH	VH
$C_{4,1}$	H	H	H	H	H
$C_{4,2}$	H	VH	VH	H	H
$C_{4,3}$	H	VH	VH	H	H
$C_{4,4}$	H	MH	H	MH	H
$C_{4,5}$	H	VH	H	VH	H
$C_{4,6}$	H	VH	H	H	MH
$C_{4,7}$	M	MH	H	MH	MH
$C_{5,1}$	MH	H	VH	H	MH
$C_{5,2}$	H	VH	H	H	H
$C_{5,3}$	H	VH	VH	VH	VH
$C_{5,4}$	H	VH	H	VH	H
$C_{5,5}$	H	VH	H	H	H
$C_{5,6}$	H	H	VH	H	H
$C_{5,7}$	H	VH	VH	VH	VH
$C_{6,1}$	H	VH	VH	H	H
$C_{6,2}$	H	VH	VH	H	H
$C_{6,3}$	H	VH	H	MH	H
$C_{6,4}$	H	VH	H	VH	H
$C_{6,5}$	H	H	H	H	MH
$C_{6,6}$	M	H	VH	VH	MH
$C_{6,7}$	MH	VH	VH	H	MH

Table 3.5: Priority weight against individual 1st level indices as given by the DMs

1st level indices, C_i	Linguistic judgment of the DMs				
	DM1	DM2	DM3	DM4	DM5
C_1	H	H	H	VH	VH
C_2	VH	H	VH	VH	VH
C_3	MH	H	H	H	MH
C_4	H	VH	VH	VH	H
C_5	VH	H	VH	H	VH
C_6	H	H	H	H	VH

Table 3.6: Appropriateness ratings against individual 2nd level indices as given by the DMs **(Alternative A_1)**

2nd level indices, $C_{i,j}$	Linguistic judgment of the DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	F	F	F	MG	G
$C_{1,2}$	F	MG	MG	MG	MG
$C_{1,3}$	G	VG	VG	VG	VG
$C_{1,4}$	F	MG	G	G	F
$C_{1,5}$	F	F	F	MP	F
$C_{1,6}$	G	MG	G	MG	G
$C_{1,7}$	MG	MG	MG	MG	MG
$C_{1,8}$	G	G	G	G	G
$C_{1,9}$	G	VG	G	VG	VG
$C_{1,10}$	MG	G	MG	G	G
$C_{1,11}$	G	G	G	G	G
$C_{1,12}$	F	G	MG	MG	G
$C_{1,13}$	F	G	MG	MG	MG
$C_{2,1}$	G	VG	VG	VG	VG
$C_{2,2}$	F	MG	G	G	F
$C_{2,3}$	F	F	F	MP	F
$C_{2,4}$	G	G	G	MG	G
$C_{2,5}$	MG	G	MG	MG	MG
$C_{2,6}$	G	G	G	G	G
$C_{2,7}$	G	VG	G	VG	VG
$C_{2,8}$	MG	G	MG	G	G
$C_{2,9}$	G	G	G	G	G
$C_{2,10}$	F	MG	F	MG	G
$C_{2,11}$	G	VG	VG	VG	VG
$C_{2,12}$	F	MG	G	G	F
$C_{2,13}$	F	F	F	MP	F
$C_{2,14}$	G	MG	G	MG	G
$C_{2,15}$	MG	MG	MG	MG	MG
$C_{2,16}$	G	G	G	G	G
$C_{2,17}$	G	VG	G	VG	VG
$C_{2,18}$	G	G	G	G	G

$C_{3,1}$	G	G	G	G	G
$C_{3,2}$	F	G	MG	MG	G
$C_{3,3}$	F	G	MG	MG	MG
$C_{3,4}$	G	VG	VG	VG	VG
$C_{3,5}$	MG	MG	G	G	G
$C_{3,6}$	MG	F	F	MP	G
$C_{3,7}$	G	G	G	MG	G
$C_{3,8}$	MG	G	MG	MG	G
$C_{3,9}$	G	G	G	G	G
$C_{3,10}$	MG	G	G	G	G
$C_{4,1}$	G	G	G	G	G
$C_{4,2}$	F	MG	F	MG	G
$C_{4,3}$	G	VG	G	VG	G
$C_{4,4}$	F	MG	G	G	F
$C_{4,5}$	F	F	F	MP	F
$C_{4,6}$	G	MG	G	MG	G
$C_{4,7}$	MG	MG	MG	MG	MG
$C_{5,1}$	G	G	G	G	G
$C_{5,2}$	G	VG	G	VG	VG
$C_{5,3}$	G	G	G	G	G
$C_{5,4}$	MG	G	MG	G	VG
$C_{5,5}$	G	G	G	G	VG
$C_{5,6}$	F	MG	F	MG	G
$C_{5,7}$	G	VG	VG	VG	VG
$C_{6,1}$	F	MG	G	G	F
$C_{6,2}$	G	F	F	MP	MP
$C_{6,3}$	G	MG	G	MG	G
$C_{6,4}$	MG	G	G	MG	MG
$C_{6,5}$	G	G	G	G	G
$C_{6,6}$	G	VG	G	VG	VG
$C_{6,7}$	G	G	MG	MG	MG

Table 3.7: Appropriateness ratings against individual 2nd level indices as given by the DMs **(Alternative A_2)**

2nd level indices, $C_{i,j}$	Linguistic judgment of the DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	G	G	G	G	G
$C_{1,2}$	G	VG	G	VG	G
$C_{1,3}$	VG	VG	VG	G	G
$C_{1,4}$	G	MG	G	G	G
$C_{1,5}$	VG	VG	VG	VG	VG
$C_{1,6}$	G	VG	G	VG	VG
$C_{1,7}$	G	G	G	G	G
$C_{1,8}$	MG	G	G	G	G
$C_{1,9}$	G	VG	G	VG	G
$C_{1,10}$	G	G	G	G	VG
$C_{1,11}$	MG	G	G	VG	VG
$C_{1,12}$	G	G	G	G	G
$C_{1,13}$	G	G	G	VG	G

$C_{2,1}$	VG	G	VG	G	G
$C_{2,2}$	G	G	G	G	G
$C_{2,3}$	VG	G	VG	VG	VG
$C_{2,4}$	G	G	G	VG	VG
$C_{2,5}$	G	G	MG	G	G
$C_{2,6}$	MG	G	G	G	G
$C_{2,7}$	G	VG	G	VG	G
$C_{2,8}$	G	G	G	VG	VG
$C_{2,9}$	MG	G	G	VG	VG
$C_{2,10}$	G	MG	G	G	G
$C_{2,11}$	G	VG	G	G	VG
$C_{2,12}$	VG	VG	VG	G	VG
$C_{2,13}$	G	MG	G	G	VG
$C_{2,14}$	VG	VG	VG	VG	VG
$C_{2,15}$	G	VG	G	VG	VG
$C_{2,16}$	G	G	G	G	G
$C_{2,17}$	MG	G	MG	MG	G
$C_{2,18}$	MG	G	G	G	G
$C_{3,1}$	G	VG	VG	VG	G
$C_{3,2}$	G	G	MG	G	VG
$C_{3,3}$	MG	G	VG	VG	VG
$C_{3,4}$	G	G	MG	G	G
$C_{3,5}$	G	G	MG	VG	G
$C_{3,6}$	VG	G	G	G	G
$C_{3,7}$	G	G	G	G	G
$C_{3,8}$	VG	G	VG	VG	VG
$C_{3,9}$	G	G	G	VG	VG
$C_{3,10}$	G	G	G	G	G
$C_{4,1}$	VG	VG	G	VG	G
$C_{4,2}$	VG	G	G	G	VG
$C_{4,3}$	MG	G	G	VG	VG
$C_{4,4}$	VG	G	G	G	G
$C_{4,5}$	G	G	G	VG	G
$C_{4,6}$	G	G	VG	G	G
$C_{4,7}$	G	G	G	G	G
$C_{5,1}$	G	G	VG	VG	VG
$C_{5,2}$	G	G	G	VG	VG
$C_{5,3}$	G	G	MG	G	G
$C_{5,4}$	G	G	G	G	G
$C_{5,5}$	G	VG	G	VG	G
$C_{5,6}$	G	G	G	VG	VG
$C_{5,7}$	G	G	G	VG	VG
$C_{6,1}$	G	MG	G	G	G
$C_{6,2}$	G	VG	G	G	VG
$C_{6,3}$	MG	G	G	G	G
$C_{6,4}$	VG	VG	G	VG	G
$C_{6,5}$	VG	G	G	G	VG
$C_{6,6}$	MG	G	G	VG	VG
$C_{6,7}$	MG	G	G	G	G

Table 3.8: Appropriateness ratings against individual 2nd level indices as given by the DMs **(Alternative A_3)**

2nd level indices, $C_{i,j}$	Linguistic judgment of the DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	MP	F	F	F	F
$C_{1,2}$	F	F	F	F	F
$C_{1,3}$	MG	MG	F	MG	MG
$C_{1,4}$	F	MG	MP	F	MG
$C_{1,5}$	G	F	MG	MG	MG
$C_{1,6}$	F	MG	F	F	F
$C_{1,7}$	G	MG	MG	MG	MG
$C_{1,8}$	MG	G	G	G	MG
$C_{1,9}$	F	MG	F	F	F
$C_{1,10}$	MG	F	MP	F	F
$C_{1,11}$	G	G	G	MG	G
$C_{1,12}$	G	G	G	G	G
$C_{1,13}$	MG	F	MG	MG	F
$C_{2,1}$	G	MG	G	MG	F
$C_{2,2}$	MP	MP	F	F	F
$C_{2,3}$	F	F	F	MP	F
$C_{2,4}$	MG	MG	F	MG	MG
$C_{2,5}$	F	MG	MP	F	MG
$C_{2,6}$	G	F	MG	MG	MG
$C_{2,7}$	F	MG	F	F	F
$C_{2,8}$	G	MG	MG	G	MG
$C_{2,9}$	MG	G	VG	G	MG
$C_{2,10}$	F	MG	F	F	MP
$C_{2,11}$	MG	F	MP	F	F
$C_{2,12}$	G	G	G	MG	G
$C_{2,13}$	G	G	G	G	G
$C_{2,14}$	MG	F	MG	MG	F
$C_{2,15}$	G	MG	G	MG	MP
$C_{2,16}$	MP	F	F	F	F
$C_{2,17}$	F	F	F	F	F
$C_{2,18}$	MG	MG	F	MG	MG
$C_{3,1}$	F	MG	MP	F	MG
$C_{3,2}$	VG	F	MG	MG	MG
$C_{3,3}$	F	MG	F	F	MP
$C_{3,4}$	VG	MG	MG	MG	MG
$C_{3,5}$	MG	G	G	G	MG
$C_{3,6}$	F	MG	F	MP	F
$C_{3,7}$	MG	F	MP	F	MP
$C_{3,8}$	G	G	G	MG	G
$C_{3,9}$	G	G	G	G	G
$C_{3,10}$	G	G	VG	G	MG
$C_{4,1}$	MG	MG	F	F	MP
$C_{4,2}$	MG	F	MP	F	F
$C_{4,3}$	MG	G	G	MG	G

$C_{4,4}$	MG	G	G	G	G
$C_{4,5}$	MG	F	MG	MG	F
$C_{4,6}$	MG	MG	G	MG	MP
$C_{4,7}$	MP	F	F	F	F
$C_{5,1}$	F	F	F	F	F
$C_{5,2}$	MG	MG	F	MG	MG
$C_{5,3}$	MP	MG	MP	F	MG
$C_{5,4}$	VG	F	MG	MG	MG
$C_{5,5}$	MG	MG	F	F	MP
$C_{5,6}$	MG	G	VG	G	MG
$C_{5,7}$	F	MG	F	F	MP
$C_{6,1}$	MG	F	MP	F	F
$C_{6,2}$	MG	G	G	MG	G
$C_{6,3}$	MG	G	G	G	G
$C_{6,4}$	MG	F	MG	MG	F
$C_{6,5}$	MG	MG	G	MG	MP
$C_{6,6}$	MP	F	F	F	F
$C_{6,7}$	MP	F	F	F	F

Table 3.9: Computed priority rating against individual 2nd level indices as given by the DMs for Alternatives A_1, A_2, A_3

2nd level metrics	A_1	A_2	A_3
	Ratings	Ratings	Ratings
$C_{1,1}$	[(3.50,4.70);6.20;(7.40,8.40)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(2.00,3.10);4.60;(6.10,7.10)]
$C_{1,2}$	[(4.10,5.10);6.60;(7.70,9.10)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.50,3.50);5.00;(6.50,6.50]
$C_{1,3}$	[(7.90,9.10);9.80;(9.90,10.0)]	[(7.30,8.70);9.60;(9.80,10.0)]	[(4.105.10);6.60;(7.70,8.10)]
$C_{1,4}$	[(4.10,5.50);7.00;(8.00,8.90)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(2.80,3.90);5.40;(6.70,7.30)]
$C_{1,5}$	[(2.00,3.10);4.60;(6.10,7.10)]	[(8.50,9.50);10.0;(10.0,10.0)]	[(4.30,5.50);7.00;(8.00,8.10)]
$C_{1,6}$	[(5.10,6.70);8.20;(8.90,9.80)]	[(7.30,8.70);9.60;(9.80,10.0)]	[(2.90,3.90);5.40;(6.80,6.90)]
$C_{1,7}$	[(4.505.50);7.00;(8.00,9.50)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(4.70,5.90);7.40;(8.30,8.50)]
$C_{1,8}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.307.10);8.60;(9.20,9.90)]	[(5.10,6.70);8.20;(8.90,8.80)]
$C_{1,9}$	[(7.30,8.70);9.60;(9.80,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.90,3.90);5.40;(6.80,6.90)]
$C_{1,10}$	[(5.10,6.70);8.20; (8.90,9.8)]	[(6.10,7.90);9.20;(9.60,10.0)]	[(2.40,3.50);5.00;(6.40,6.10)]
$C_{1,11}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(6.50,7.90);9.00;(9.40,9.90)]	[(5.30,7.10);8.60;(9.20,9.00)]
$C_{1,12}$	[(4.50,5.90);7.40;(8.30,9.30)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.50,7.50);9.00;(9.50,9.10)]

$C_{1,13}$	[(4.30,5.50);7.00;(8.00,9.20)]	[(6.10,7.90);9.20;(9.60,10.0)]	[(3.70,4.70);6.20;(7.40,7.30)]
$C_{2,1}$	[(7.90,9.10);9.80;(9.90,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(4.50,5.90);7.40;(8.30,7.80)]
$C_{2,2}$	[(4.10,5.50);7.00;(8.00,8.90)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(1.50,2.70);4.20;(5.70,6.10)]
$C_{2,3}$	[(2.00,3.10);4.60;(6.10,7.10)]	[(7.90,9.10);9.80;(9.90,10.0)]	[(2.00,3.10);4.60;(6.10,6.10)]
$C_{2,4}$	[(5.30,7.10);8.60;(9.20,9.90)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(4.10,5.10);6.60;(7.70,8.10)]
$C_{2,5}$	[(4.70,5.90);7.40;(8.30,9.60)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(2.80,3.90);5.40;(6.70,7.30)]
$C_{2,6}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(4.30,5.50);7.00;(8.00,8.10)]
$C_{2,7}$	[(7.30,8.70);9.60;(9.80,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.90,3.90);5.40;(6.80,6.90)]
$C_{2,8}$	[(5.10,6.70);8.20;(8.90,9.80)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(4.90,6.30);7.80;(8.60,8.60)]
$C_{2,9}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(6.50,7.90);9.00;(9.40,9.90)]	[(5.70,7.10);8.40;(9.00,8.80)]
$C_{2,10}$	[(3.90,5.10);6.60;(7.70,8.80)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(2.40,3.50);5.00;(6.40,6.00)]
$C_{2,11}$	[(7.90,9.10);9.80;(9.90,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.40,3.50);5.00;(6.40,6.10)]
$C_{2,12}$	[(4.10,5.50);7.00;(8.00,8.90)]	[(7.90,9.10);9.80;(9.90,10.0)]	[(5.30,7.10);8.60;(9.20,9.00)]
$C_{2,13}$	[(2.00,3.10);4.60;(6.10,7.10)]	[(5.90,7.50);8.80;(9.30,9.90)]	[(5.50,7.50);9.00;(9.50,9.10)]
$C_{2,14}$	[(5.10,6.70);8.20;(8.90,9.80)]	[(8.50,9.50);10.0;(10.0,10.0)]	[(3.70,4.70);6.20;(7.40,7.30)]
$C_{2,15}$	[(4.50,5.50);7.00;(8.00,9.50)]	[(7.30,8.70);9.60;(9.80,10.0)]	[(4.00,5.50);7.00;(7.90,6.90)]
$C_{2,16}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(2.00,3.10);4.60;(6.10,6.50)]
$C_{2,17}$	[(7.30,8.70);9.60;(9.80,10.0)]	[(4.90,6.30);7.80;(8.60,9.70)]	[(2.50,3.50);5.00;(6.50,6.500]
$C_{2,18}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(4.10,5.100;6.60;(7.70,8.10)]
$C_{3,1}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(7.30,8.70);9.60;(9.80,10.0)]	[(2.80,3.90);5.40;(6.70,7.30)]
$C_{3,2}$	[(4.50,5.90);7.40;(8.30,9.30)]	[(5.90,7.50);8.80;(9.30,9.90)]	[(4.90,5.90);7.20;(8.10,8.10)]
$C_{3,3}$	[(4.30,5.50);7.00;(8.00,9.20)]	[(7.10,8.30);9.20;(9.50,9.90)]	[(2.40,3.50);5.00;(6.40,6.00)]
$C_{3,4}$	[(7.90,9.10);9.80;(9.90,10.0)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(5.30,6.30);7.60;(8.40,8.50)]
$C_{3,5}$	[(5.10,6.70);8.20;(8.90,9.80)]	[(5.90,7.50);8.80;(9.30,9.90)]	[(5.10,6.70);8.20;(8.90,8.80)]
$C_{3,6}$	[(3.00,4.30);5.80;(7.00,8.00)]	[(6.10,7.90);9.20;(9.60,10.0)]	[(2.40,3.50);5.00;(6.40,6.50)]
$C_{3,7}$	[(5.30,7.10);8.60;(9.20,9.90)]	[(5.50,7.50);9.00;(9.5010.0)]	[(1.90,3.10);4.60;(6.00,5.20)]
$C_{3,8}$	[(4.90,6.30);7.80;(8.60,9.70)]	[(7.90,9.10);9.80;(9.90,10.0)]	[(5.30,7.10);8.60;(9.20,9.00)]

$C_{3,9}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(5.50,7.50);9.00;(9.50,9.10)]
$C_{3,10}$	[(5.30,7.10);8.60;(9.20,9.90)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.90,7.50);8.80;(9.30,8.80)]
$C_{4,1}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(7.30,8.70);9.60;(9.80,10.0)]	[(2.80,3.90);5.40;(6.70,6.00)]
$C_{4,2}$	[(3.90,5.10);6.60;(7.70,8.80)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.40,3.50);5.00;(6.40,6.10)]
$C_{4,3}$	[(6.70,8.30);9.40;(9.70,10.0)]	[(6.50,7.90;9.00;(9.409.900)]	[(5.10,6.70);8.20;(8.90,9.00)]
$C_{4,4}$	[(4.10,5.50);7.00;(8.00,8.90)]	[(6.10,7.90);9.20;(9.60,10.0)]	[(5.30,7.10);8.60;(9.20,9.10)]
$C_{4,5}$	[(2.00,3.10);4.60;(6.10,7.10)]	[(6.10,7.90);9.20;(9.60,10.0)]	[(3.70,4.70);6.20;(7.40,7.30)]
$C_{4,6}$	[(5.10,6.70);8.20;(8.90,9.80)]	[(6.10,7.90);9.20;(9.60,10.0)]	[(3.80,5.10);6.60;(7.60,6.90)]
$C_{4,7}$	[(4.50,5.50);7.00;(8.00,9.50)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(2.00,3.10);4.60;(6.10,6.50)]
$C_{5,1}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(7.30,8.70);9.60;(9.8010.0)]	[(2.50,3.50);5.00;(6.50,6.50)]
$C_{5,2}$	[(7.30,8.70);9.60;(9.80,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(4.10,5.10);6.60;(7.70,8.10)]
$C_{5,3}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(2.30,3.50);5.00;(6.30,7.30)]
$C_{5,4}$	[(5.70,7.10);8.40;(9.00,9.80)]	[(5.50,7.50);9.00;(9.50,10.0)]	[(4.90,5.90);7.20;(8.10,8.10)]
$C_{5,5}$	[(6.10,7.90);9.20;(9.60,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.80,3.90);5.40;(6.70,6.00)]
$C_{5,6}$	[(3.90,5.10);6.60;(7.70,8.80)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(5.70,7.10);8.40;(9.00,8.80)]
$C_{5,7}$	[(7.90,9.10);9.80;(9.90,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(2.40,3.50);5.00;(6.406.00)]
$C_{6,1}$	[(4.10,5.50);7.00;(8.00,8.90)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(2.40,3.50);5.00;(6.40,6.10)]
$C_{6,2}$	[(2.10,3.50);5.00;(6.30,7.20)]	[(6.70,8.30);9.40;(9.7010.0)]	[(5.10,6.70);8.20;(8.90,9.00)]
$C_{6,3}$	[(5.10,6.70);8.20;(8.90,9.80)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(5.30,7.10);8.60;(9.20,9.10)]
$C_{6,4}$	[(4.90,6.30);7.80;(8.60,9.70)]	[(7.30,8.70);9.60;(9.80,10.0)]	[(3.70,4.70);6.20;(7.40,7.30)]
$C_{6,5}$	[(5.50,7.50);9.00;(9.50,10.0)]	[(6.70,8.30);9.40;(9.70,10.0)]	[(3.80,5.10);6.60;(7.60,6.90)]
$C_{6,6}$	[(7.30,8.70);9.60;(9.80,10.0)]	[(6.50,7.90);9.00;(9.40,9.90)]	[(2.00,3.10);4.60;(6.10,6.50)]
$C_{6,7}$	[(4.90,6.30);7.80(8.60,9.70)]	[(5.30,7.10);8.60;(9.20,9.90)]	[(2.00,3.10);4.60;(6.10,6.50)]

Table 3.10: Computed Priority weight against individual 2nd level indices as given by the DMs for Alternatives A_1, A_2, A_3

2nd level metrics	A_1 Weightages	A_2 Weightages	A_3 Weightages
$C_{1,1}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{1,2}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{1,3}$	[(0.49,0.63);0.78;(0.86,0.97)]	[(0.49,0.63);0.78;(0.86,0.97)]	[(0.49,0.63);0.78;(0.86,0.97)]
$C_{1,4}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{1,5}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{1,6}$	[(0.49,0.59);0.72;(0.81,0.92)]	[(0.49,0.59);0.72;(0.81,0.92)]	[(0.49,0.59);0.72;(0.81,0.92)]
$C_{1,7}$	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]
$C_{1,8}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{1,9}$	[(0.73,0.87);0.96;(0.98,1.00)]	[(0.73,0.87);0.96;(0.98,1.00)]	[(0.73,0.87);0.96;(0.98,1.00)]
$C_{1,10}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{1,11}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{1,12}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{1,13}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{2,1}$	[(0.51,0.67);0.82;(0.89,0.98)]	[(0.51,0.67);0.82;(0.89,0.98)]	[(0.51,0.67);0.82;(0.89,0.98)]
$C_{2,2}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{2,3}$	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]
$C_{2,4}$	[(0.43,0.55);0.70;(0.80,0.92)]	[(0.43,0.55);0.70;(0.80,0.92)]	[(0.43,0.55);0.70;(0.80,0.92)]
$C_{2,5}$	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]
$C_{2,6}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{2,7}$	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]
$C_{2,8}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{2,9}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{2,10}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{2,11}$	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]

$C_{2,12}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{2,13}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{2,14}$	[(0.59,0.75);0.88;(0.93,0.99)]	[(0.59,0.75);0.88;(0.93,0.99)]	[(0.59,0.75);0.88;(0.93,0.99)]
$C_{2,15}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{2,16}$	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]
$C_{2,17}$	[(0.51,0.63);0.76;(0.84,0.93)]	[(0.51,0.63);0.76;(0.84,0.93)]	[(0.51,0.63);0.76;(0.84,0.93)]
$C_{2,18}$	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]
$C_{3,1}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{3,2}$	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]
$C_{3,3}$	[(0.73,0.87);0.96;(0.98,1.00)]	[(0.73,0.87);0.96;(0.98,1.00)]	[(0.73,0.87);0.96;(0.98,1.00)]
$C_{3,4}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{3,5}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{3,6}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{3,7}$	[(0.51,0.67);0.82;(0.89,0.98)]	[(0.51,0.67);0.82;(0.89,0.98)]	[(0.51,0.67);0.82;(0.89,0.98)]
$C_{3,8}$	[(0.73,0.87);0.96;(0.98,1.00)]	[(0.73,0.87);0.96;(0.98,1.00)]	[(0.73,0.87);0.96;(0.98,1.00)]
$C_{3,9}$	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]
$C_{3,10}$	[(0.51,0.63);0.76;(0.84,0.93)]	[(0.51,0.63);0.76;(0.84,0.93)]	[(0.51,0.63);0.76;(0.84,0.93)]
$C_{4,1}$	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]	[(0.55,0.75);0.90;(0.95,1.00)]
$C_{4,2}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{4,3}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{4,4}$	[(0.51,0.67);0.82;(0.89,0.98)]	[(0.51,0.67);0.82;(0.89,0.98)]	[(0.51,0.67);0.82;(0.89,0.98)]
$C_{4,5}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{4,6}$	[(0.59,0.75);0.88;(0.93,0.90)]	[(0.59,0.75);0.88;(0.93,0.90)]	[(0.59,0.75);0.88;(0.93,0.90)]
$C_{4,7}$	[(0.43,0.55);0.70;(0.80,0.92)]	[(0.43,0.55);0.70;(0.80,0.92)]	[(0.43,0.55);0.70;(0.80,0.92)]
$C_{5,1}$	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]	[(0.57,0.71);0.84;(0.90,0.98)]
$C_{5,2}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{5,3}$	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]

$C_{5,4}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{5,5}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{5,6}$	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]	[(0.61,0.79);0.92;(0.96,1.00)]
$C_{5,7}$	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]	[(0.79,0.91);0.98;(0.99,1.00)]
$C_{6,1}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{6,2}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{6,3}$	[(0.59,0.75);0.88;(0.93,0.99)]	[(0.59,0.75);0.88;(0.93,0.99)]	[(0.59,0.75);0.88;(0.93,0.99)]
$C_{6,4}$	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]	[(0.67,0.83);0.94;(0.97,1.00)]
$C_{6,5}$	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]	[(0.53,0.71);0.86;(0.92,0.99)]
$C_{6,6}$	[(0.59,0.71);0.82;(0.88,0.94)]	[(0.59,0.71);0.82;(0.88,0.94)]	[(0.59,0.71);0.82;(0.88,0.94)]
$C_{6,7}$	[(0.63,0.75);0.86;(0.91,0.98)]	[(0.63,0.75);0.86;(0.91,0.98)]	[(0.63,0.75);0.86;(0.91,0.98)]

Table 3.11: Computed weighted normalized interval-valued fuzzy decision matrix

Indices	Alternatives	Weights normalized matrix
C_1	A_1	[(0.121,0.257);0.438;(0.613,0.933)]
	A_2	[(0.157,0.329);0.527;(0.694,1.000)]
	A_3	[(0.091,0.203);0.369;(0.548,0.769)]
C_2	A_1	[(0.152,0.299);0.476;(0.645,0.945)]
	A_2	[(0.186,0.359);0.545;(0.706,1.000)]
	A_3	[(0.104,0.218);0.378;(0.553,0.744)]
C_3	A_1	[(0.105,0.236);0.423;(0.601,0.942)]
	A_2	[(0.132,0.283);0.479;(0.652,0.980)]
	A_3	[(0.086,0.195);0.363;(0.539,0.760)]
C_4	A_1	[(0.117,0.248);0.423;(0.600,0.917)]
	A_2	[(0.164,0.334);0.527;(0.696,1.000)]
	A_3	[(0.094,0.204);0.365;(0.543,0.729)]
C_5	A_1	[(0.196,0.375);0.564;(0.713,0.981)]

	A_2	[(0.206,0.397);0.592;(0.738,1.000)]
	A_3	[(0.112,0.228);0.390;(0.556,0.727)]
C_6	A_1	[(0.116,0.260);0.450;(0.6260.937)]
	A_2	[(0.150,0.322);0.527;(0.6971.000)]
	A_3	[(0.085,0.198);0.367;(0.5460.739)]

Table 3.12: Computed Positive ideal and negative ideal solutions

Indices	Alternatives	Positive ideal solution (A^*)	Negative ideal solution (A^-)
C_1	A_1	[(0.157,0.329);0.527;(0.694,1.00)]	[(0.091,0.203);0.369;(0.548,0.769)]
	A_2		
	A_3		
C_2	A_1	[(0.186,0.359);0.545;(0.706,1.00)]	[(0.104,0.218);0.378;(0.553,0.774)]
	A_2		
	A_3		
C_3	A_1	[(0.132,0.283);0.479;(0.652,0.980)]	[(0.086,0.195);0.363;(0.539,0.760)]
	A_2		
	A_3		
C_4	A_1	[(0.164,0.334);0.527;(0.696,1.00)]	[(0.094,0.204);0.365;(0.543,0.729)]
	A_2		
	A_3		
C_5	A_1	[(0.206,0.397);0.592;(0.738,1.00)]	[(0.112,0.228);0.390;(0.556,0.727)]
	A_2		
	A_3		
C_6	A_1	[(0.150,0.322);0.527;(0.697,1.00)]	[(0.085,0.198);0.367;(0.546,0.739)]
	A_2		
	A_3		

Table 3.13: Computed Ideal Separation matrix (D^*) and anti-ideal separation matrix (D^-)

Indices	Alternatives	(D^*)	(D^-)
C_1	A_1	0.879	0.842
	A_2	0.843	0.909
	A_3	0.909	0.678
C_2	A_1	0.848	0.841
	A_2	0.814	0.896
	A_3	0.896	0.670
C_3	A_1	0.875	0.856
	A_2	0.848	0.894
	A_3	0.894	0.674
C_4	A_1	0.883	0.823
	A_2	0.836	0.906
	A_3	0.906	0.635
C_5	A_1	0.804	0.869
	A_2	0.794	0.888
	A_3	0.888	0.615
C_6	A_1	0.884	0.852
	A_2	0.850	0.915
	A_3	0.915	0.654

Table 3.14: Computed Values of Γ_i , ς_i and CI_i by proposed IVFN-TOPSIS method

Alternatives	Γ_i	ς_i	CI_i	Ranking Order
A_1	1.018354	2.04291	3.061264	**2**
A_2	0.921711	1.940421	2.862131	**1**
A_3	1.379031	2.431502	3.810534	**3**

3.2 Green Supply Chain Performance Appraisement and Benchmarking using Fuzzy Grey Relation Method

3.2.1 Coverage

Recently, green supply chain management (GSCM) has led to an increasing body of research in relation to both external influences leading to the adaptation of green supply chain management practices, and their impact on firm's overall performance. In last decades, green performance measurement has become a part of decision-making scenario in order to check and compare ongoing firm's performance with the prescribed standard from the aspects of amendment as well as improvement of green issues and practices for acquisition of unified green goal of candidate industries.

In this context, an efficient performance appraisement framework (index system) has been conceptualized from the resource of existing literature to appraise and benchmark the green performance extent of candidate industries running under similar green supply chain architecture. In this work, on account of the ill-defined criterions and inherent vagueness associated with subjectivity of evaluation criterions (evaluation indices); the assessment (evaluated score) of the expert panel have been acquired in terms of linguistic assessment which have been finally transformed into generalized Triangular Fuzzy Number (TFN) set. The fuzzy transformation of the linguistic data helped in data analysis supported by the fuzzy mathematics in order to facilitate the said decision-making.

A fuzzy based computation module embedded with Grey Relation Method (GRM) has been explored in this work from the prospectus of evaluation, appraisal and benchmarking the preferred green supply chain performance of candidate industries operating under common green practices. Finally, an empirical case study has been led from the perspective of checking feasibility as well as effectiveness of the proposed decision-making approach.

3.2.2 Problem Definition

In today's emerging era of market globalization, manufacturing industries are being motivated to concentrate on green supply chain initiatives to maintain the pollution ratio, to facilitate proper decision making under constituted rules and government legislations, and to effectively as well as efficiently utilize assets of the organization under the non/minimum/zero pollution circumstances conjunctively (Chiou et al., 2011; Min and Galle, 1997).

Literature was found rich in addressing various aspects of GSCM. Constructs (framework) of GSC, green supplier selection etc. were adequately studied by the pioneers. Limited attempt was made in evaluating overall GSC performance extent for manufacturing industries. It is felt that successful implementation of GSC initiatives necessitates performance appraisement as well as benchmarking of best practices. The ongoing performance extent of the entire GSC needs to be monitored. In this context, application of decision-making tools and techniques deserves mention.

Decision-making is a very complicated task which drags the sense of the people brain in conflict way whenever the decision is made under the given circumstances for preferred candidate alternatives. A decision support system can be made with the help of decision tools, techniques, software and methodology to evaluate, appraise and benchmark of the given alternatives. The current problem has been defined as a compatible decision making situation which aims at evaluating (appraising) organizational GSC performance extent; comparing 'green performance' level of candidate industries who have adapted similar GSC initiatives and performance benchmarking amongst them.

In the present work, a green supply chain performance appraisement index system/module (consisting of evaluation indices: measures and metrics) has been conceptualized from the resources of literature survey aiming to measure the green performance status of preferred candidate industries under similar GSC circumstances.

Due to vagueness, impreciseness, inconsistency as well as incompleteness associated in assessing various subjective evaluation indices/initiatives; the decision support system that has been proposed here, relies on expert judgment of the Decision-Makers (DMs). The decision making has been effectively carried out through analyzing the assessment (subjective information) of the expert panel in linguistic terminology which has been further transformed into generalized 'Triangular Fuzzy Number Set' (TFNs). The fuzzy based computation module in combination with Grey Relation Analysis (GRA) has been successfully explored here towards evaluation, appraisal and benchmarking the preferred candidate industries running under common GSC structure. Finally, am empirical study has been presented here to support application feasibility of the proposed approach.

3.2.3 Fuzzy Grey Relation Method

A fuzzy embedded grey relation method has been proposed here towards performance appraisement and benchmarking of organizational GSC. The work explores theory of Triangular Fuzzy Numbers (TFNs) along with grey relation method. This section provides detailed mathematics of the proposed decision support module.

3.2.3.1 Triangular Fuzzy Numbers

In a universe of discourse X , a fuzzy subset A of X is defined by a membership function $f_A(x)$, which maps each element x in X to a real number in the interval $[0,1]$. The function value $f_A(x)$ represents the grade of membership of x in A.

Definition: 1 if a fuzzy set A on the universe R of real numbers satisfies the following conditions, it known as a fuzzy number.

(1) A is a convex fuzzy set;

(2) There is only one x_0 that satisfies $f_A(x_0)=1$; and

(3) $f_A(x)$ is continuous in an interval.

Based on the extension principle, we can derive the arithmetic of fuzzy numbers as shown in (Zadeh, 1965; 1975; 1976).

A fuzzy number A in real line is a triangular fuzzy number if, its membership function $f_A(x):\Re \rightarrow [0,1]$ is with $(-\infty < c \le a \le b <, \infty)$ .The triangular fuzzy number can be denoted by (c, a, b) ; (Dubois and Prade, 1978)

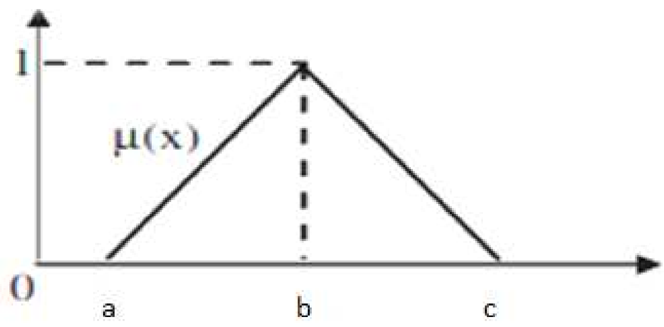

Fig. 3.3: A Membership function of triangular fuzzy number

$$f_A(x) = \begin{cases} \dfrac{x-c}{a-c}, & if \ c \le x \le a \\ \dfrac{x-b}{a-b}, & if \ b \le x \le c \\ 0, & otherwise \end{cases}$$ (3.29)

The parameter gives the maximal grade of $f_A(x)$ i.e., $f_A(x)=1$; it is the most probable value of the evaluation data. In addition, 'c', 'b' are the lower and upper bounds of the available area for the evaluation data. They are used to reflect the fuzziness of the evaluation data. The narrower the interval $[c,b]$ the lower is the fuzziness of the evaluation data.

Suppose that $A_1=(c_1,a_1,b_1)$ and $A_2=(c_2,a_2,b_2)$ are two trapezoidal fuzzy numbers, then the operational rules of the triangular fuzzy numbers A_1 and A_2 are shown as follows (Zadeh, 1965):

Fuzzy Addition:

$$A_1 \oplus A_2 = (c_1,a_1,b_1) \oplus (c_2,a_2,b_3) = (c_1+c_2, a_1+a_2, b_1+b_2)$$ (3.30)

Fuzzy subtraction:

$$A_1 \Theta A_2 = (c_1,a_1,b_1) \oplus (c_2,a_2,b_3) = (c_1-b_2, a_1-a_2, b_1-c_2)$$ (3.31)

Fuzzy multiplication:

$$k \otimes A_2 = k \otimes (c_2,a_2,b_3) = k \times c_2, k \times a_2, k \times b_2 \qquad k \in \Re, \quad k \ge 0,$$ (3.32)

$$A_1 \otimes A_2 = (c_1,a_1,b_1) \otimes (c_2,a_2,b_3) = c_1 \times c_2, a_1 \times a_2, b_1 \times b_2 \qquad c_1 \ge 0, \quad k \ge 0,$$ (3.33)

Fuzzy division:

$$A_1 \phi A_2 = (c_1,a_1,b_1) \phi (c_2,a_2,b_3) = \left(\frac{c_1}{b_2}, \frac{a_1}{a_2}, \frac{b_1}{c_2} \right)$$ (3.34)

In MCDM, linguistic terminology is the communication platform of DMs which is employed in subjective decision environments. In MCDM, two preferences are mostly assessed by DMs in linguistic terms; the appropriateness rating and importance weights against respective criteria/

indices. Furthermore, these linguistic values can be characterized by appropriate fuzzy numbers (Zadeh, 1975; 1976) in fuzzy decision modeling. Depending on practical needs, DMs may apply one or both of them. In this reporting, linguistic values have been characterized by triangular fuzzy numbers in order to evaluate appropriateness rating (performance extent) and importance weights (priority) of all criteria and the appropriateness of alternatives versus various subjective criteria against the alternatives (Kaufmann and Gupta, 1991; Lee, 1999; Önüt et al., 2008; Dubois and Prade, 1978). Various criteria can be considered in a multi-criteria evaluation problem. Criteria used should be identified by considering the specific requirements of the problem. The criteria can be classified into two categories: (1) subjective criteria, which have linguistic/qualitative definition; (2) objective criteria, which are defined in monetary/quantitative terms.

3.2.3.2 Ranking of Triangular Fuzzy Numbers

In fuzzy decision making environment, derivation of the ranking order with respect to the alternatives under consideration is very important and essential. For matching the fuzzy MCDM algorithm developed in this work, the graded mean integration representation method proposed by (Chen and Hsieh, 2000) has been used to rank the final ratings of alternatives. Let, $A_i = (c_1, a_1, b_1),\ i = 1,2,3,4............n,$ be n triangular fuzzy numbers. By the graded mean integration representation method, the graded mean integration representation $R(A_i)$ of A_i is:

$$R(A_i) = \frac{(c_i, 4a_i, b_i)}{6} \tag{3.35}$$

Suppose $R(A_i)\ and\ R(A_j)$ are the graded mean integration representations of the triangular fuzzy numbers $A_i\ and\ A_j$ respectively.

Define that $A_i > A_j \Leftrightarrow R(A_i) > R(A_j),$

$$A_i < A_j \Leftrightarrow R(A_i) < R(A_j),$$

$$A_i = A_j \Leftrightarrow R(A_i) = R(A_j).$$

3.2.3.3 Procedural Steps of Fuzzy Grey Relation Method

Procedural steps for fuzzy based grey relation method have been summarized below.

Step 1: Solve the subjective weights of all criteria above the alternative level

Let $w_{kj} = (c_{kj}, a_{kj}, b_{kj}), 0 \le c_{kj} \le a_{kj} \le b_{kj} \le 1,\ k = 1,2,...,n;\ j = 1,2,...,r,$ be the importance degrees assigned to criterion C_k by the decision-maker DM_j. Then, the weight w_k of C_k can be calculated by

$$w_k = \left(\frac{1}{r}\right) \otimes \left(w_{k1} \oplus w_{k2} \oplus ... \oplus w_{kj} \oplus ... \oplus w_{kr}\right) \tag{3.36}$$

By the extension principle, w_k is also a triangular fuzzy number. That is, let

$$c_k = \sum_{j=1}^{r} c_{kj} / r,$$
$$a_k = \sum_{j=1}^{r} a_{kj} / r, \tag{3.37}$$
$$b_k = \sum_{j=1}^{r} b_{kj} / r$$

Then $w_k = (c_k, a_k, b_k)$

Step 2: Solve the superiority ratings of all alternatives versus all criteria above the alternative level

Let $M_{ikj} = (q_{ikj}, o_{ikj}, f_{ikj}), 0 \le q_{ikj} \le o_{ikj} \le f_{ikj}; i = 1,2,...,m; k = 1,2,...,n;\ j = 1,2,...,r,$ be the linguistic ratings assigned to alternative A_i by the decision-maker D_j for the subjective criterion C_k. Then, the linguistic rating M_{ik} of alternative A_i for the subjective criterion C_k can be calculated by

$$M_{ik} = \left(\frac{1}{r}\right) \otimes \left(M_{ik1} \oplus ... \oplus M_{ikj} \oplus ... \oplus M_{ikr}\right), i = 1,2,...,m; k = 1,2,...,n. \tag{3.38}$$

$$q_{ik} = \sum_{j=1}^{r} \frac{q_{ikj}}{r}$$
$$o_{ik} = \sum_{j=1}^{r} \frac{o_{ikj}}{r}$$
$$f_{ik} = \sum_{j=1}^{r} \frac{f_{ikj}}{r},$$

Then

$$M_{ik} = (q_{ik}, o_{ik}, f_{ik}), i = 1,2,...,m; k = 1,2,...,n. \tag{3.39}$$

Step 3: Calculate the integration weights of all criteria above alternative level

Let $w_k = (c_k, a_k, b_k), k = 1,2,...,n,$ denote the subjective weights of n criteria above alternative level. Allow $u_k, k = 1,2,...,n,$ to be the normalized subjective weight of all criteria above the alternative level. Define

$$u_k = \frac{R(w_k)}{\sum_{k=1}^{n} R(w_k)}, k = 1,2,...,n. \tag{3.40}$$

Here $R(F_i)$ is the graded mean integration representation method of fuzzy number $F_i = (c_i, a_i, b_i), i = 1,2,..., p$

$$R(F_i) = \frac{c_i + 4a_i + b_i}{6} \tag{3.41}$$

Step 4: Calculate the grey relational grade of all compared alternatives to reference alternative

Let $X_i, i = 1,2,...,m$ be the superiority ratings of m alternatives described by triangular fuzzy numbers of linguistic values characterized by triangular fuzzy numbers.

Let $X_0 = (X_{01}, X_{02},..., X_{0n})$ and $X_i = (X_{i1}, X_{i2},..., X_{in})(i = 1,2,...,m)$ be the referential sequence and comparative sequences, respectively. In addition, allow $d_{0i}(k)$ to be the distance of fuzzy difference between the referential pattern X_{0k} and a comparative pattern X_{ik}, where X_{0k} is the fuzzy message of X_0 and X_{ik} is the fuzzy message of X_i at point (criterion) k. Define $d_{0i}(k)$ as

$$d_{0i}(k) = d(X_{0k}, X_{ik})$$

Let $F_i = (c_i, a_i, b_i), F_j = (c_j, a_j, b_j)$ be two triangular fuzzy numbers. Based on (Chen and Hsieh, 2000) method, the distance between F_i and F_j, denoted by $d(F_i, F_j)$, is

$$d\left(F_i, F_j\right) = \left\{ \left[\left(c_i - c_j\right)^2 + \left(a_i - a_j\right)^2 + \left(b_i - b_j\right)^2 \right] \Big/ 4 \right\}^{1/2} \quad (3.42)$$

Step 5: The normalization of the criterion under the alternative is carried out by below Eq. 3.43 and Eq. 3.46).

For the beneficial criterion:

$$T_{ik} = \left(\frac{h_{ik}}{t_k}, \frac{e_{ik}}{t_k}, \frac{g_{ik}}{t_k}\right) \quad (3.43)$$

Where, $T_{ik} = \max_i [g_{ik}]$

For the non-beneficial criterion:

$$T_{ik} = \left(\frac{t_k}{g_{ik}}, \frac{t_k}{e_{ik}}, \frac{t_k}{h_{ik}}\right) \quad (3.44)$$

Where, $T_{ik} = \min_i [h_{ik}]$

$X_{ik} = \{T_{ik,} \;\; i = 1, 2, 3 \ldots\ldots\ldots\ldots m; \quad k = 1, 2 \ldots\ldots\ldots\ldots\ldots n\}$

Here $X_{ik} = \{T_{ik,} \;\; i = 1, 2, 3 \ldots\ldots\ldots\ldots m; \quad k = 1, 2 \ldots\ldots\ldots\ldots\ldots n\}$, donates the superiority rating of alternatives A_i for criterion C_K

Step 6: Define the grey relation coefficient (GRC) of X_0 and X_i at point (criterion) k as

$$\gamma\left(X_{0k}, X_{ik}\right) = \frac{\left(\min_i \min_k d_{0i}(k) + \xi \max_i \max_k d_{0i}(k)\right)}{\left(d_{0i}(k) + \xi \max_i \max_k d_{0i}(k)\right)} \quad (3.45)$$

The GRC can be utilized to reflect the grey relation of X_i compared to X_0 at point (criterion) k.

In aforesaid equation, $\max_i \max_k d_{0i}(k)$ and $\min_i \min_k d_{0i}(k)$ denote the maximum and the minimum elements of the $d_{0i}(k)$, respectively. The distinguishing coefficient ξ, which is between 0 and 1, can be used to change the dimension of relative values of $\gamma\left(X_{0k}, X_{ik}\right)$. In general, $\xi = 0.5$ is better when the relative conditions among series and elements are uncertain (Deng, 1989).

Step 7: Define the GRG of X_i compared to X_0 as

$$\gamma(X_0, X_i) = \sum_{k=1}^{n} u_k \times \gamma(X_{0k}, X_{ik}) \tag{3.46}$$

Here u_k is the integration weight of criterion C_k.

When the number of GRC is too much and messages are too discrete, the GRG is used to characterize the grey relational grade of X_i compared to X_0. When the GRG is larger indicates that the series X_i and X_0 are highly related. On the contrary, these two series are lowly related when the GRG is littler.

3.2.4 Empirical Illustration

In this research, a green supply chain performance appraisement module (evaluation index system) (Table 3.15) adapted from the work by (Bhattacharya et al., 2013) has been explored. The definitions/explanations of various performance indices (at level I, II and III) have been illustrated at the end of this chapter. An empirical case study has been carried out to test efficiency as well as effectiveness of proposed methodology. In this context, it has been assumed that a committee of five DMs (expert panel), DM_1, DM_2, DM_3, DM_4, DM_5 has been formed from different managerial level of the organization i.e. quality assurance, production, material evaluation, marketing, product design and assembly etc. Also, it has been assumed that there have been four preferred candidate industries/enterprises A_1, A_2, A_3, A_4 (running under similar GSC architecture). Next, expert panel has been instructed to start assessing various performance indices starting from the 3^{rd} level hierarchical model (*Level I, Level II and Level III performance indices*) along with the primitive aim to derive performance ranking order (benchmarking) of candidate industries from GSC performance perspective. In the 3^{rd} level hierarchical model: Organizational Commitment (C_1), Eco Design (C_2), Green Supply Chain Process (C_3), Social Performance (C_4), Sustainable Performance (C_5) thus have been considered at the Level I followed by Level II metrics; and individual Level II metrics have been followed by Level III metrics which encompass a number of supply chain performance sub-indicators (indices), for the aforesaid four preferred candidate industries/enterprises A_1, A_2, A_3, A_4 (running under similar SC architecture).

The constructed green supply chain performance appraisement module consists of various evaluation indices. These indices being subjective in nature; the aforesaid decision-making problem has been modified to work under fuzzy environment. Fuzzy logic based grey relation method is an approach which was pointed out by (Liao et al., 2013). The expert team of DMs plays an important role in providing decision information in relation to various SC performance indices (their weight as well as rating). The priority weights and corresponding appropriateness ratings (performance estimates) of individual SC performance indices have been expressed in linguistic variables collected from the decision-making group. The expert judgment (linguistic information) has been transformed into appropriate fuzzy number set in accordance with a predefined fuzzy representative scale as shown in (Table 3.16).

The procedural steps of green performance appraisement as well as benchmarking have been provided below.

Step 1: Gathering information from the expert group in relation to performance rating and importance weights of different evaluation indices using linguistic terms

In course of evaluating importance weights of numerous supply chain performance indices (from I to III level), as well as appropriateness rating for II level and III level indices; a committee of five decision-makers (DMs), DM_1, DM_2,…,DM_5 has been formed to express their subjective preferences (evaluation score) in linguistic terms shown in (Tables 3.16); which have been further transformed into triangular fuzzy number set (1-6 point scale). The appropriateness rating (in linguistic terms) against III to II level evaluation metrics as assigned by the expert panel have been furnished in (Tables 3.17-3.21), for alternative A_1, A_2 and A_3, respectively. The decision-makers assessed an priority importance weights for III level to I level green supply chain performance indices for preferred candidate alternatives A_1, A_2 and A_3 which have been revealed in (Tables 3.22-3.24).

Step 2: Approximation of the linguistic evaluation information by triangular fuzzy number set

Using the concept of triangular fuzzy numbers in fuzzy set theory, the linguistic variables have been transformed into corresponding appropriate fuzzy numbers as shown in (Table 3.16). Next, based on simple fuzzy average rule (FAR); the aggregated fuzzy priority weights for (*III level to I level*) have been computed for preferred candidate alternatives A_1, A_2 and A_3 and A_4; revealed in (Tables 3.27-3.29). Similarly, aggregated performance ratings (*II to III level*) evaluated metrics have been computed for preferred candidate alternative A_1, A_2 and A_3 and A_4 industries; revealed in (Tables 3.25-3.26). Exploring the fuzzy weighted average rule, performance ratings of different evaluation indices (starting from *III level to I level*) have been computed.

Appropriateness rating for each of the 2nd level evaluation index U_{ij} (rating of j_{th} index) has been computed as follows:

$$U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ijk}} \tag{3.47}$$

U_{ijk} is denoted as the computed fuzzy appropriateness rating (obtained using Eq. 3.38) against k_{th} index (at 3rd level) which is under j_{th} index in the 2nd level and under i_{th} index in the 1st level. w_{ijk} is the aggregated fuzzy weight against k_{th} index (at 3rd level).

Appropriateness rating for each of the 1st level evaluation index U_i (rating of i_{th} index) has been computed as follows:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{3.48}$$

U_{ij} is denoted as the computed fuzzy appropriateness rating (obtained from Eq. 3.47) against j_{th} index (at 2nd level) which is under i_{th} index in the 1st level. w_{ij} is the aggregated fuzzy weight against j_{th} index (at 2nd level) which is under i_{th} index at 1st level.

The computed ratings have been shown in (Table 3.30), for alternative A_1, A_2 and A_3, respectively.

Step 3: Development of MCDM Matrix

Then, a fuzzy multi-criteria group decision making (FMCGDM) matrix has been developed based on four alternatives and five green supply chain performance criterions (Level I indices).

Step 4: Normalization

All of the indices have been assumed beneficial in nature and expressed in terms of triangular fuzzy numbers set and usually these numbers belong to the interval [0; 1]. Normalization is indeed required for the case of decision making situation involving both beneficial as well as adverse (cost) evaluation criterions to make a compatible balance between the two. In the present work, all evaluation criterions have been assumed beneficial in nature; and, hence no need to normalize the constructed decision-making matrix by employing Eq. 3.43.

Step 6: Computation of Integration Weights

Integration weights of all criterions (Level I) have been computed by explored the (Eqs. 3.40-3.41).

Step 7: Computation of Grey Relation Coefficients (GRC)

Grey Relation Coefficients (GRC) have been computed (Eq. 3.45) against individual criterions with respect to preferred candidate alternatives A_1, A_2 and A_3 and A_4; revealed in (Table 3.31) and finally, Grey Relation Grades (GRG) of prescribed alternatives have been computed by employing the Eq. 3.46; revealed in Table 3.32.

Step 8: Ranking Order of Preferred Candidate Alternatives

As per the analysis it has been found that the third alternative (A_3) appeared as best ranked amongst the four possible alternatives (Table 3.32, Fig. 3.4).

3.2.5 Managerial Implications

In today's global business scenario, organizations (manufacturing sectors) are receiving tremendous attention on serious issues in GSCM activities e.g. minimization of waste heat, recovery of hot air and avoiding of enormous hazard/toxic/unwanted materials/stuff, etc. from the perspective of the clean overcast. Therefore, green supply chain performance measurement against these issues leads a role to evaluate, appraise and benchmark preferred alternatives industries under similar green supply chain initiatives. There exists a gap of research in perspective of estimating overall GSC performance extent. In order to fill up this gap, the present work has adapted a three-level appraisement module based on multi-indices which could facilitate the manager in evaluating, appraisal and benchmarking the preferred industries operating under the similar green supply chain type. In this work, grey relation method has been explored in conjunction with TFN for evaluation and benchmarking the green performance of preferred candidate industries. This research work may facilitate the manager whenever the manager experiences the problem to evaluate green performance level and benchmark best green practices of candidate industries. It has been fully realized that the proposed method can provide reliable consequence and be also fruitfully applied as one of the Multi-Criteria Decision

Making (MCDM) decision support methodologies in different fields. Consequently, this multi-criteria analysis method is of practical use in solving real life multi-criteria analysis decision problems.

3.2.6 Concluding Remarks

Application of fuzzy set theory in the group decision making procedure provides an effective and efficient way towards modeling a multiple indices framework for the evaluation and appraisal of green performance against preferred candidate industries. In last decades, decision support tools, techniques and methodologies have been applied to solve numerous decision making scenarios related to GSC. Therefore, GSCM has been recognized as a monitoring approach which creates the win-win situation for organizations and helps to create consumers worth/value, satisfactory responses, better enterprises image, enhancing productivity, and enhanced competitiveness. In this context, hierarchical appraisement platform has been established here for an evaluation and benchmarking of GSC performance of preferred candidate industries.

The judgments (subjective information) collected from expert panels in linguistic form; have further been transformed into fuzzy scale. This research has explored grey relation method in conjunction with TFNs theory towards facilitating evaluation and benchmarking the green performance of preferred candidate industries. The proposed methodology enables the committee to incorporate and aggregate multiple fuzzy information assessed by decision-makers. Finally, an empirical study has been carried out in order to exhibit feasibility as well as effectiveness of the proposed methodology. The main contributions of the aforesaid research have been highlighted below.

1. Exploration of Triangular Fuzzy Number set (TFNs) in conjunction with grey relation method towards appraisement and benchmarking of preferred candidate alternative industries operating under the similar green supply chain initiatives.
2. The proposed module tackled and handled inherent vagueness, impreciseness and inconsistency entailed in subjective evaluated information from expert panel against subjective criterion (evaluation indices).

Table 3.15: Green Supply Chain Performance Appraisement Modeling; [Source: Bhattacharya e t al., 2013]

Goal (C)	Measures(1st level indices)	Metrics (2nd level indices)	Metrics (3rd level indices)
GSC Performance Measurement	Organizational Commitment, C_1	Top management commitment, $C_{1,1}$	
		Middle management commitment, $C_{1,2}$	
		Cross functional cooperation, $C_{1,3}$	
		Employee involvement, $C_{1,4}$	
	Eco Design, C_2	Design of products for reduced consumption of material/energy, $C_{2,1}$	
		Design of products for reuse, recycle, recovery of material, component parts, $C_{2,2}$	
		Design of products to avoid or reduce use of hazardous products and/or their manufacturing process, $C_{2,3}$	
	Green supply chain process, C_3	Green purchasing, $C_{3,1}$	Providing design specification to suppliers with environmental requirements, $C_{3,11}$
			Cooperation with suppliers to environmental objectives, $C_{3,12}$
			Environmental audit for supplier internal management, $C_{3,13}$
			Supplier ISO 14000 certification, $C_{3,14}$
			Second tier supplier environmental friendly practices evaluation, $C_{3,15}$
		Green marketing, $C_{3,2}$	Cooperation with customer for eco -design, $C_{3,21}$
			Cooperation with customer for cleaner production, $C_{3,22}$
			Cooperation with customer for green packaging, $C_{3,23}$
			Cooperation with customer for least energy consumption for logistics, $C_{3,24}$
		Investment recovery, $C_{3,3}$	Investment recovery of excess inventory, $C_{3,31}$

			Sales of scrap and used materials, $C_{3,32}$
			Sales of excess capital equipment, $C_{3,33}$
		Environmental process, $C_{3,4}$	Environmental compliance and audit procedure, $C_{3,41}$
			ISO 14000 certification, $C_{3,42}$
			Environmental management system, $C_{3,43}$
			Eco leveling of products, $C_{3,44}$
	Social performance,C_4	Business ethics, $C_{4,1}$	
		CSR activities, $C_{4,2}$	
		Employment generation, $C_{4,3}$	
		Positive image, $C_{4,4}$	
	Sustainable performance,C_5	Environmental performance, $C_{5,1}$	Reduction of emission, $C_{5,11}$
			Reduction of usage of harm full materials, $C_{5,12}$
			Reduction of accidents, $C_{5,13}$
			Recycling of materials, $C_{5,14}$
			Sale of art design for reverse logistics, $C_{5,15}$
		Economic performance, $C_{5,2}$	Energy consumption, $C_{5,21}$
			Cost of procurement, $C_{5,22}$
			Water usage, $C_{5,23}$
			Reduction of disposal cost, $C_{5,24}$
			Reduction of waste, $C_{5,25}$
		Operational performance, $C_{5,3}$	Optimum design, $C_{5,31}$
			Minimum inventory, $C_{5,32}$
			Capacity utilization, $C_{5,33}$
			Improved quality, $C_{5,34}$
			Effective reverse logistics, $C_{5,35}$
			Reduction of time for recycling, $C_{5,36}$

Table 3.16: Definitions of linguistic variables for the ratings and priority importance of each criterion: Corresponding fuzzy representation

Linguistic variables	Linguistic variables	Triangular fuzzy numbers
Very Poor (VP)	Very Low (VL)	(0,0,0.167)
Poor (P)	Low (L)	(0,0.167,0.333)
Moderately Poor (MP)	Medium Low (ML)	(0.167,0.333,0.5)
Fair (F)	Medium (M)	(0.333,0.5,0.668)
Moderately Good (MG)	Medium High (MH)	(0.5,0.668,0.835)
Good (G)	High (H)	(0.668,0.835,1)
Very Good (VG)	Very High (VH)	(0.835,1,1)

Table 3.17: Priority rating (in linguistic scale) against individual 3rd level indices assigned by DMs for alternative A_1

3rd level indices	Priority rating (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{3,11}$	VG	MG	VG	MG	F
$C_{3,12}$	VG	MG	F	MP	G
$C_{3,13}$	G	MG	G	MP	G
$C_{3,14}$	F	MG	F	G	G
$C_{3,15}$	MG	G	VG	VG	VG
$C_{3,21}$	F	F	VG	MP	G
$C_{3,22}$	F	MP	VG	VG	G
$C_{3,23}$	G	VG	G	MP	VG
$C_{3,24}$	G	VG	G	VG	MP
$C_{3,31}$	F	F	F	VP	MP
$C_{3,32}$	G	G	F	F	F
$C_{3,33}$	G	F	F	VG	G
$C_{3,41}$	MG	MG	MG	VG	G
$C_{3,42}$	MG	MG	MG	F	MG
$C_{3,43}$	G	MG	F	F	MG
$C_{3,44}$	VG	G	F	VG	G
$C_{5,11}$	VG	G	G	VG	MG
$C_{5,12}$	G	G	F	MG	MG

$C_{5,13}$	F	MG	F	MG	F
$C_{5,14}$	G	MG	F	F	F
$C_{5,15}$	F	F	VG	VG	MG
$C_{5,21}$	MG	F	VG	VG	MG
$C_{5,22}$	MG	VG	MG	MG	MG
$C_{5,23}$	G	F	MG	MG	VG
$C_{5,24}$	G	G	F	G	VG
$C_{5,25}$	F	MG	G	F	F
$C_{5,31}$	G	MG	G	F	G
$C_{5,32}$	G	G	F	MG	VG
$C_{5,33}$	G	VG	F	MG	VG
$C_{5,34}$	F	F	F	F	F
$C_{5,35}$	MG	F	MG	VG	G
$C_{5,36}$	MG	VG	MG	VG	G

Table 3.18: Priority rating (in linguistic scale) against individual 3rd level indices assigned by DMs for alternative A_2

3rd level indices	Priority rating (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{3,11}$	F	MP	VG	VG	G
$C_{3,12}$	G	VG	G	MP	VG
$C_{3,13}$	G	VG	G	MG	MP
$C_{3,14}$	F	F	F	VP	MP
$C_{3,15}$	G	G	VG	F	VG
$C_{3,21}$	G	F	VG	VG	VG
$C_{3,22}$	MG	MG	MG	VG	G
$C_{3,23}$	MG	MG	MG	F	MG
$C_{3,24}$	G	MG	F	F	MG
$C_{3,31}$	VG	G	VG	VG	VG
$C_{3,32}$	VG	G	G	VG	MG
$C_{3,33}$	MG	F	MG	F	VG
$C_{3,41}$	MG	F	VG	F	VG

$C_{3,42}$	F	VG	VG	MG	MG
$C_{3,43}$	VG	VG	VG	MG	MG
$C_{3,44}$	VG	MG	MG	MG	VG
$C_{5,11}$	F	MG	MG	VG	VG
$C_{5,12}$	G	F	MG	VG	MG
$C_{5,13}$	MG	G	VG	VG	F
$C_{5,14}$	MG	G	F	G	F
$C_{5,15}$	G	F	MG	VG	MG
$C_{5,21}$	VG	F	MG	VG	MG
$C_{5,22}$	F	F	F	F	MG
$C_{5,23}$	F	MG	VG	G	VG
$C_{5,24}$	G	G	VG	MG	VG
$C_{5,25}$	F	MG	G	F	F
$C_{5,31}$	VG	VG	G	F	G
$C_{5,32}$	MG	G	F	G	F
$C_{5,33}$	G	F	MG	VG	MG
$C_{5,34}$	VG	F	MG	VG	MG
$C_{5,35}$	MG	F	MG	VG	G
$C_{5,36}$	MG	MG	MG	VG	G

Table 3.19: Priority rating (in linguistic scale) against individual 3rd level indices assigned by DMs for alternative A_3

3rd level indices	Priority rating (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{3,11}$	MG	VG	G	MG	G
$C_{3,12}$	MG	G	MG	G	VG
$C_{3,13}$	G	VG	G	MG	F
$C_{3,14}$	MG	MP	G	VG	F
$C_{3,15}$	VG	MP	MG	G	VG
$C_{3,21}$	G	VG	MG	MG	VG
$C_{3,22}$	F	VG	MG	MG	G
$C_{3,23}$	F	G	MG	MG	F
$C_{3,24}$	F	F	MG	F	F

$C_{3,31}$	F	F	F	G	MG
$C_{3,32}$	G	MG	G	MG	MG
$C_{3,33}$	MG	MG	MG	F	MG
$C_{3,41}$	F	MG	F	F	VG
$C_{3,42}$	F	VG	VG	G	VG
$C_{3,43}$	G	VG	VG	F	F
$C_{3,44}$	VG	MG	VG	MG	VG
$C_{5,11}$	F	MG	MG	VG	VG
$C_{5,12}$	G	F	MG	VG	G
$C_{5,13}$	MG	G	G	VG	MG
$C_{5,14}$	MG	MG	MG	G	F
$C_{5,15}$	G	G	VG	G	F
$C_{5,21}$	VG	F	G	F	G
$C_{5,22}$	F	F	MG	VG	G
$C_{5,23}$	F	F	G	VG	MG
$C_{5,24}$	G	G	VG	F	VG
$C_{5,25}$	F	MG	G	F	F
$C_{5,31}$	VG	VG	G	F	G
$C_{5,32}$	VG	VG	F	MG	VG
$C_{5,33}$	G	VG	F	MG	VG
$C_{5,34}$	F	F	F	F	F
$C_{5,35}$	MG	F	MG	VG	G
$C_{5,36}$	MG	MG	MG	VG	G

Table 3.20: Priority rating (in linguistic scale) against individual 3rd level indices assigned by DMs for alternative A_4

3rd level indices	Priority rating (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{3,11}$	MG	MG	MG	VG	G
$C_{3,12}$	MG	MG	MG	F	MG
$C_{3,13}$	G	MG	F	F	MG
$C_{3,14}$	VG	G	F	VG	MG
$C_{3,15}$	VG	G	G	VG	MG
$C_{3,21}$	G	G	F	MG	G
$C_{3,22}$	F	MG	F	MG	F
$C_{3,23}$	G	MG	F	MG	F
$C_{3,24}$	F	MG	VG	G	MG
$C_{3,31}$	MG	MG	VG	MG	MG
$C_{3,32}$	MG	G	MG	MG	MG
$C_{3,33}$	G	F	MG	G	VG
$C_{3,41}$	F	MG	F	F	VG
$C_{3,42}$	F	VG	VG	G	VG
$C_{3,43}$	G	VG	VG	F	F
$C_{3,44}$	G	MG	F	F	F
$C_{5,11}$	F	F	VG	MG	MG
$C_{5,12}$	MG	F	VG	MG	MG
$C_{5,13}$	MG	MG	MG	G	MG
$C_{5,14}$	G	MG	MG	MG	VG
$C_{5,15}$	G	G	VG	G	F
$C_{5,21}$	G	MG	F	F	F
$C_{5,22}$	F	F	VG	MG	MG
$C_{5,23}$	MG	F	VG	MG	MG
$C_{5,24}$	MG	MG	MG	G	MG
$C_{5,25}$	G	MG	MG	MG	VG
$C_{5,31}$	F	G	F	F	VG
$C_{5,32}$	F	VG	VG	G	VG
$C_{5,33}$	G	VG	VG	F	F
$C_{5,34}$	G	MG	F	MG	F
$C_{5,35}$	F	F	VG	MG	MG
$C_{5,36}$	MG	F	VG	G	MG

Table 3.21: Priority rating (in linguistic scale) against individual 2nd level indices assigned by DMs

2nd level indices	Priority rating (in linguistic scale) of 2nd level indices assigned by DMs for alternative A_1				
	DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	MG	MG	MG	F	MG
$C_{1,2}$	G	MG	F	F	MG
$C_{1,3}$	F	G	F	VG	VG
$C_{1,4}$	MG	F	F	VG	MG
$C_{2,1}$	G	F	VG	MG	MG
$C_{2,2}$	G	G	VG	VG	G
$C_{2,3}$	G	G	VG	MG	G
$C_{4,1}$	MG	F	F	MG	MG
$C_{4,2}$	MG	F	VG	F	VG
$C_{4,3}$	MG	F	F	MG	MG
$C_{4,4}$	G	F	VG	MG	MG
2nd level indices	Priority rating (in linguistic scale) of 2nd level indices assigned by DMs for alternative A_2				
$C_{1,1}$	MG	F	MG	F	VG
$C_{1,2}$	MG	F	VG	F	VG
$C_{1,3}$	MG	F	F	MG	MG
$C_{1,4}$	G	F	VG	VG	MG
$C_{2,1}$	G	G	VG	MG	MG
$C_{2,2}$	F	VG	VG	MG	MG
$C_{2,3}$	VG	VG	VG	MG	MG
$C_{4,1}$	MG	F	F	MG	MG
$C_{4,2}$	G	F	VG	VG	G
$C_{4,3}$	G	G	VG	MG	G
$C_{4,4}$	F	MG	MG	VG	VG
2nd level indices	Priority rating (in linguistic scale) of 2nd level indices assigned by DMs for alternative A_3				
$C_{1,1}$	G	MG	G	MG	F
$C_{1,2}$	VG	G	VG	G	F
$C_{1,3}$	VG	G	VG	G	G
$C_{1,4}$	G	G	G	G	F
$C_{2,1}$	F	MG	F	MG	F
$C_{2,2}$	G	MG	G	MG	F
$C_{2,3}$	G	MG	G	MG	F
$C_{4,1}$	G	VG	VG	G	F
$C_{4,2}$	VG	MG	VG	G	G
$C_{4,3}$	F	MG	MG	VG	VG
$C_{4,4}$	G	F	MG	VG	G

2nd level indices	Priority rating (in linguistic scale) of 2nd level indices assigned by DMs for alternative A_4				
$C_{1,1}$	G	MG	F	F	MG
$C_{1,2}$	VG	G	F	VG	MG
$C_{1,3}$	VG	G	G	VG	MG
$C_{1,4}$	G	G	F	MG	G
$C_{2,1}$	F	MG	F	MG	F
$C_{2,2}$	G	MG	F	MG	F
$C_{2,3}$	G	MG	G	MG	MG
$C_{4,1}$	G	MG	F	F	MG
$C_{4,2}$	VG	G	F	VG	MG
$C_{4,3}$	VG	G	G	VG	MG
$C_{4,4}$	G	G	F	MG	G

Table 3.22: Priority weight (in linguistic scale) against individual 3rd level indices assigned by DMs for alternatives A_1, A_2, A_3, A_4

3rd level indices	Priority weight (in linguistic scale) of 3rd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{3,11}$	VH	H	MH	H	H
$C_{3,12}$	H	H	MH	H	H
$C_{3,13}$	MH	MH	H	MH	H
$C_{3,14}$	VH	VH	MH	MH	MH
$C_{3,15}$	VL	H	MH	MH	L
$C_{3,21}$	M	H	VH	H	L
$C_{3,22}$	ML	MH	VH	VH	H
$C_{3,23}$	MH	ML	VH	VH	H
$C_{3,24}$	MH	ML	MH	ML	VH
$C_{3,31}$	MH	MH	MH	H	VH
$C_{3,32}$	H	MH	H	H	ML
$C_{3,33}$	L	L	VL	MH	ML
$C_{3,41}$	MH	MH	VH	MH	ML
$C_{3,42}$	MH	MH	VH	MH	MH
$C_{3,43}$	MH	MH	VH	H	H
$C_{3,44}$	MH	MH	MH	H	H
$C_{5,11}$	VH	H	MH	ML	VH
$C_{5,12}$	VH	MH	MH	ML	MH

$C_{5,13}$	ML	MH	ML	ML	MH
$C_{5,14}$	ML	L	VH	H	MH
$C_{5,15}$	MH	MH	VH	H	MH
$C_{5,21}$	H	ML	H	H	H
$C_{5,22}$	MH	VH	VH	MH	MH
$C_{5,23}$	MH	VH	MH	ML	MH
$C_{5,24}$	MH	MH	VH	ML	VH
$C_{5,25}$	MH	VH	VH	MH	VH
$C_{5,31}$	MH	VH	MH	MH	VH
$C_{5,32}$	VH	VH	MH	VH	MH
$C_{5,33}$	VH	MH	VH	MH	MH
$C_{5,34}$	VH	ML	VH	MH	VH
$C_{5,35}$	MH	ML	MH	VH	VH
$C_{5,36}$	MH	VH	MH	MH	MH

Table 3.23: Priority weight (in linguistic scale) against individual 2nd level indices assigned by DMs for alternatives A_1, A_2, A_3, A_4

2nd level indices	Priority weight (in linguistic scale) of 2nd level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	MH	H	H	H	VH
$C_{1,2}$	MH	MH	MH	H	ML
$C_{1,3}$	MH	MH	MH	MH	ML
$C_{1,4}$	MH	MH	VH	MH	ML
$C_{2,1}$	MH	MH	VH	MH	MH
$C_{2,2}$	MH	MH	VH	H	H
$C_{2,3}$	MH	MH	MH	H	H
$C_{3,1}$	VH	H	MH	ML	VH
$C_{3,2}$	VH	MH	MH	ML	MH
$C_{3,3}$	MH	VH	MH	MH	MH
$C_{3,4}$	MH	VH	H	MH	H
$C_{4,1}$	VH	H	MH	ML	VH
C4,2	MH	MH	MH	H	H
C4,3	VH	H	MH	ML	VH
C4,4	VH	MH	MH	ML	MH
$C_{5,1}$	MH	MH	VH	MH	MH
$C_{5,2}$	MH	MH	VH	H	H
$C_{5,3}$	MH	MH	MH	H	H

Table 3.24: Priority weight (in linguistic scale) against individual 1st level indices assigned by DMs for alternatives A_1, A_2, A_3, A_4

1st level indices	Priority weight (in linguistic scale) of 1st level indices assigned by DMs				
	DM1	DM2	DM3	DM4	DM5
C_1	VH	H	MH	ML	VH
C_2	VH	MH	MH	ML	MH
C_3	MH	MH	ML	VH	MH
C_4	MH	MH	ML	MH	H
C_5	VH	MH	MH	MH	VH

Table 3.25: Aggregated priority fuzzy rating of 3rd level indices for alternatives

3rd level indices	Aggregated priority fuzzy rating			
	A_1	A_2	A_3	A_4
$C_{3,11}$	[0.601,0.767,0.868]	[0.568,0.734,0.834]	[0.634,0.801,0.934]	[0.601,0.768,0.901]
$C_{3,12}$	[0.501,0.667,0.801]	[0.635,0.801,0.900]	[0.634,0.801,0.934]	[0.467,0.634,0.802]
$C_{3,13}$	[0.534,0.701,0.867]	[0.568,0.734,0.867]	[0.601,0.768,0.901]	[0.467,0.634,0.801]
$C_{3,14}$	[0.500,0.668,0.834]	[0.233,0.367,0.534]	[0.501,0.667,0.801]	[0.634,0.801,0.901]
$C_{3,15}$	[0.735,0.901,0.967]	[0.668,0.834,0.934]	[0.601,0.767,0.867]	[0.701,0.868,0.967]
$C_{3,21}$	[0.467,0.634,0.767]	[0.701,0.867,0.934]	[0.668,0.834,0.934]	[0.567,0.735,0.901]
$C_{3,22}$	[0.568,0.734,0.834]	[0.601,0.768,0.901]	[0.567,0.734,0.868]	[0.400,0.567,0.735]
$C_{3,23}$	[0.635,0.801,0.900]	[0.467,0.634,0.802]	[0.467,0.634,0.801]	[0.467,0.634,0.801]
$C_{3,24}$	[0.635,0.801,0.900]	[0.467,0.634,0.801]	[0.366,0.534,0.701]	[0.567,0.734,0.868]
$C_{3,31}$	[0.233,0.367,0.534]	[0.802,0.967,1.000]	[0.433,0.601,0.768]	[0.567,0.734,0.868]
$C_{3,32}$	[0.467,0.634,0.801]	[0.701,0.868,0.967]	[0.567,0.735,0.901]	[0.534,0.701,0.868]
$C_{3,33}$	[0.567,0.734,0.867]	[0.500,0.667,0.801]	[0.467,0.634,0.802]	[0.601,0.768,0.901]
$C_{3,41}$	[0.601,0.768,0.901]	[0.567,0.734,0.834]	[0.467,0.634,0.768]	[0.467,0.634,0.768]
$C_{3,42}$	[0.467,0.634,0.802]	[0.601,0.767,0.868]	[0.701,0.867,0.934]	[0.701,0.867,0.934]
$C_{3,43}$	[0.467,0.634,0.801]	[0.701,0.867,0.934]	[0.601,0.767,0.867]	[0.601,0.767,0.867]
$C_{3,44}$	[0.668,0.834,0.934]	[0.634,0.801,0.901]	[0.701,0867,0.934]	[0.433,0.601,0.768]
$C_{5,11}$	[0.701,0.868,0.967]	[0.601,0.767,0.868]	[0.601,0.767,0.868]	[0.500,0.667,0.801]
$C_{5,12}$	[0.534,0.701,0.868]	[0.567,0.734,0.868]	[0.601,0.768,0.901]	[0.534,0.701,0.835]
$C_{5,13}$	[0.400,0.567,0.735]	[0.634,0.801,0.901]	[0.634,0.801,0.934]	[0.534,0.701,0.868]
$C_{5,14}$	[0.433,0.601,0.768]	[0.500,0.668,0.834]	[0.500,0.668,0.835]	[0.601,0.768,0.901]
$C_{5,15}$	[0.567,0.734,0.834]	[0.567,0.734,0.868]	[0.634,0.801,0.934]	[0.634,0.801,0.934]

$C_{5,21}$	[0.601,0.767,0.868]	[0.601,0.767,0.868]	[0.567,0.734,0.867]	[0.433,0.601,0.768]
$C_{5,22}$	[0.567,0.734,0.868]	[0.366,0.534,0.701]	[0.534,0.701,0.834]	[0.500,0.667,0.801]
$C_{5,23}$	[0.567,0.734,0.868]	[0.634,0.801,0.901]	[0.534,0.701,0.834]	[0.534,0.701,0.835]
$C_{5,24}$	[0.634,0.801,0.934]	[0.701,0.868,0.967]	[0.668,0.834,0.934]	[0.534,0.701,0.868]
$C_{5,25}$	[0.433,0.601,0.768]	[0.433,0.601,0.768]	[0.433,0.601,0.768]	[0.601,0.768,0.901]
$C_{5,31}$	[0.567,0.735,0.901]	[0.668,0.834,0.934]	[0.668,0.834,0.934]	[0.500,0.667,0.801]
$C_{5,32}$	[0.601,0.768,0.901]	[0.500,0.668,0.834]	[0.668,0.834,0.901]	[0.701,0.867,0.934]
$C_{5,33}$	[0.634,0.801,0.901]	[0.567,0.734,0.868]	[0.634,0.801,0.901]	[0.601,0.767,0.867]
$C_{5,34}$	[0.333,0.500,0.668]	[0.601,0.767,0.868]	[0.333,0.500,0.668]	[0.467,0.634,0.801]
$C_{5,35}$	[0.567,0.734,0.868]	[0.567,0.734,0.868]	[0.567,0.734,0.868]	[0.500,0.667,0.801]
$C_{5,36}$	[0.668,0.834,0.934]	[0.601,0.768,0.901]	[0.601,0.768,0.901]	[0.567,0.734,0.868]

Table 3.26: Computed fuzzy priority rating of 2nd level indices for alternatives

2nd level indices	Computed fuzzy priority rating			
	A_1	A_2	A_3	A_4
$C_{1,1}$	[0.467,0.634,0.802]	[0.500,0.667,0.801]	[0.534,0.701,0.868]	[0.467,0.634,0.801]
$C_{1,2}$	[0.467,0.634,0.801]	[0.567,0.734,0.834]	[0.668,0.834,0.934]	[0.634,0.801,0.901]
$C_{1,3}$	[0.601,0.767,0.867]	[0.433,0.601,0.768]	[0.735,0.901,1.000]	[0.701,0.868,0.967]
$C_{1,4}$	[0.500,0.667,0.801]	[0.634,0.801,0.901]	[0.601,0.768,0.934]	[0.567,0.735,0.901]
$C_{2,1}$	[0.567,0.734,0.868]	[0.634,0.801,0.934]	[0.400,0.567,0.735]	[0.400,0.567,0.735]
$C_{2,2}$	[0.735,0.901,1.000]	[0.601,0.767,0.868]	[0.534,0.701,0.868]	[0.467,0.634,0.801]
$C_{2,3}$	[0.668,0.835,0.967]	[0.701,0.867,0.934]	[0.534,0.701,0.868]	[0.567,0.735,0.901]
$C_{3,1}$	[0.356,0.727,1.347]	[0.335,0.685,1.271]	[0.380,0.762,1.397]	[0.358,0.730,1.359]
$C_{3,2}$	[0.377,0.742,1.300]	[0.366,0.726,1.316]	[0.341,0.688,1.268]	[0.322,0.661,1.259]
$C_{3,3}$	[0.206,0.527,1.233]	[0.418,0.885,1.668]	[0.281,0.661,1.453]	[0.316,0.725,1.535]
$C_{3,4}$	[0.350,0.715,1.340]	[0.404,0.796,1.384]	[0.399,0.788,1.372]	[0.355,0.719,1.303]
$C_{4,1}$	[0.433,0.601,0.768]	[0.433,0.601,0.768]	[0.668,0.834,0.934]	[0.467,0.634,0.801]
$C_{4,2}$	[0.567,0.734,0.834]	[0.668,0.834,0.934]	[0.701,0.868,0.967]	[0.634,0.801,0.901]
$C_{4,3}$	[0.433,0.601,0.768]	[0.668,0.835,0.967]	[0.601,0.767,0.868]	[0.701,0.868,0.967]
$C_{4,4}$	[0.567,0.734,0.868]	[0.601,0.767,0.868]	[0.601,0.768,0.901]	[0.567,0.735,0.901]
$C_{5,1}$	[0.335,0.713,1.393]	[0.346,0.739,1.431]	[0.360,0.762,1.476]	[0.340,0.728,1.432]
$C_{5,2}$	[0.372,0.724,1.283]	[0.362,0.708,1.253]	[0.364,0.711,1.264]	[0.350,0.689,1.246]
$C_{5,3}$	[0.386,0.726,1.248]	[0.402,0.749,1.271]	[0.400,0.746,1.248]	[0.386,0.725,1.224]

Table 3.27: Computed fuzzy priority weight of 3rd level indices for alternatives A_1, A_2, A_3, A_4

3rd level indices	Computed fuzzy priority weight
$C_{3,11}$	[0.668,0.835,0.967]
$C_{3,12}$	[0.634,0.802,0.967]
$C_{3,13}$	[0.534,0.701,0.868]
$C_{3,14}$	[0.567,0.734,0.834]
$C_{3,15}$	[0.300,0.434,0.601]
$C_{3,21}$	[0.501,0.667,0.800]
$C_{3,22}$	[0.601,0.767,0.867]
$C_{3,23}$	[0.601,0.767,0.867]
$C_{3,24}$	[0.434,0.600,0.734]
$C_{3,31}$	[0.601,0.768,0.901]
$C_{3,32}$	[0.534,0.701,0.867]
$C_{3,33}$	[0.100,0.233,0.400]
$C_{3,41}$	[0.467,0.634,0.768]
$C_{3,42}$	[0.534,0.701,0.835]
$C_{3,43}$	[0.634,0.801,0.934]
$C_{3,44}$	[0.567,0.735,0.901]
$C_{5,11}$	[0.601,0.767,0.867]
$C_{5,12}$	[0.467,0.634,0.768]
$C_{5,13}$	[0.267,0.433,0.601]
$C_{5,14}$	[0.401,0.567,0.700]
$C_{5,15}$	[0.567,0.734,0.868]
$C_{5,21}$	[0.568,0.735,0.900]
$C_{5,22}$	[0.567,0.734,0.834]
$C_{5,23}$	[0.467,0.634,0.768]
$C_{5,24}$	[0.567,0.734,0.834]
$C_{5,25}$	[0.668,0.834,0.901]
$C_{5,31}$	[0.601,0.767,0.868]
$C_{5,32}$	[0.668,0.834,0.901]
$C_{5,33}$	[0.567,0.734,0.834]
$C_{5,34}$	[0.601,0.767,0.834]
$C_{5,35}$	[0.567,0.734,0.834]
$C_{5,36}$	[0.500,0.667,0.801]

Table 3.28: Computed fuzzy priority weight of 2nd level indices for alternatives A_1, A_2, A_3, A_4

2^{nd} level indices	Computed fuzzy priority weight
$C_{1,1}$	[0.668,0.835,0.967]
$C_{1,2}$	[0.467,0.634,0.801]
$C_{1,3}$	[0.433,0.601,0.768]
$C_{1,4}$	[0.500,0.667,0.801]
$C_{2,1}$	[0.567,0.734,0.868]
$C_{2,2}$	[0.634,0.801,0.934]
$C_{2,3}$	[0.567,0.735,0.901]
$C_{3,1}$	[0.601,0.767,0.867]
$C_{3,2}$	[0.500,0.667,0.801]
$C_{3,3}$	[0.567,0.734,0.868]
$C_{3,4}$	[0.634,0.801,0.934]
$C_{4,1}$	[0.601,0.767,0.867]
$C_{4,2}$	[0.567,0.735,0.901]
$C_{4,3}$	[0.601,0.767,0.867]
$C_{4,4}$	[0.500,0.667,0.801]
$C_{5,1}$	[0.567,0.734,0.868]
$C_{5,2}$	[0.634,0.801,0.934]
$C_{5,3}$	[0.567,0.735,0.901]

Table 3.29: Computed fuzzy priority weight of 1st level indices for alternatives A_1, A_2, A_3, A_4

1^{st} level indices	Computed fuzzy priority weight
C_1	[0.601,0.767,0.867]
C_2	[0.500,0.667,0.801]
C_3	[0.500,0.667,0.801]
C_4	[0.467,0.634,0.801]
C_5	[0.634,0.801,0.901]

Table 3.30: Computed fuzzy priority rating of 1st level indices for alternatives A_1, A_2, A_3, A_4

1st level indices	C_1	C_2	C_3
A_1	[0.312,0.671,1.317]	[0.432,0.826,1.447]	[0.214,0.678,1.968]
A_2	[0.331,0.701,1.331]	[0.421,0.811,1.393]	[0.253,0.774,2.127]
A_3	[0.386,0.792,1.500]	[0.321,0.658,1.261]	[0.234,0.727,2.071]
A_4	[0.358,0.748,1.431]	[0.312,0.645,1.243]	[0.225,0.710,2.057]
1st level indices	C_4	C_5	
A_1	[0.328,0.664,1.224]	[0.239,0.721,1.997]	
A_2	[0.390,0.758,1.340]	[0.242,0.732,2.012]	
A_3	[0.425,0.810,1.390]	[0.245,0.739,2.028]	
A_4	[0.392,0.760,1.351]	[0.234,0.713,1.985]	

Table 3.31: Computed Grey Relational Coefficient (GRC)

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	0.3339	0.9997	0.3353	0.3337	0.4314
A_2	0.3733	0.7483	0.9995	0.5965	0.6188
A_3	0.9993	0.3529	0.5485	0.9993	1.0023
A_4	0.5756	0.3348	0.4784	0.6166	0.3476

Table 3.32: Alternative ranking based on GRG

Alternatives	GRG	Ranking order
A_1	0.4819	**3**
A_2	0.6581	**2**
A_3	0.7928	**1**
A_4	0.4678	**4**

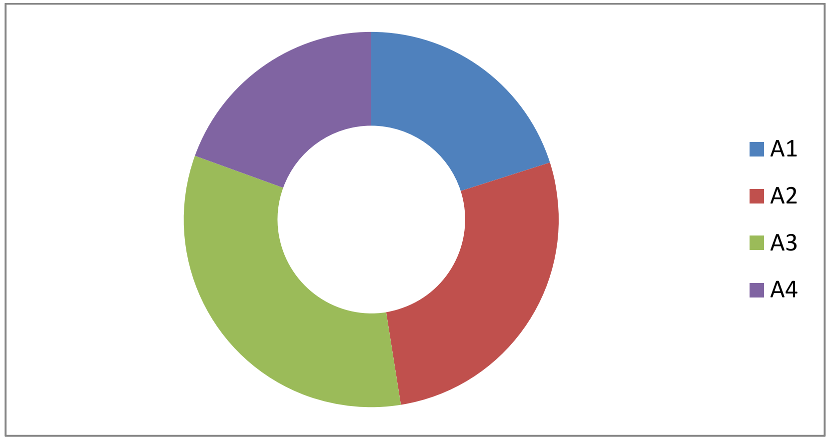

Fig 3.4: Doughnut chart analysis revealed the raking order in descending order in accordance to the value of GRG of respective alternatives

Definitions of Green Supply Chain Performance Measures (1st level indices)

Measures	Definition	References
Organizational commitment, C_1	It is the individual's psychological attachment to the organization. It predicts work variables such as turnover, organizational citizenship behavior and job performance.	[Source: http://en.wikipedia.org/wiki/Organizational_commitment]
Eco design, C_2	It is an approach to design a product with special consideration for the environmental impacts of the product during its whole lifecycle. In a life cycle assessment, the life cycle of a product is usually divided into procurement, manufacture, use and disposal.	[Sources: http://en.wikipedia.org/wiki/Eco-design]
Green supply chain process, C_3	It entitles those activities which associate: product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers and end-of-life of product after its useful life) being concerned with green (sustainability).	[Sources: http://www.greenrecycling.co.uk/]
Social performance, C_4	It may be defined as an effective translation of an institution's mission into practice in line with accepted social values. It is the system for translating mission into practice.	[Sources: http://www.microcredgroup.com/social-performance/]
Sustainable performance, C_5	It is environmental and social sustainability philosophy on products as well as production processes. It develops solutions that comply with the highest environmental standards.	[Sources: http://www.pirelli.com/corporate/en/deepen/glossary/tyre_ghil.page]

Definitions of Green Supply Chain Performance Metrics (2nd level indices)

Metric (2nd level)	Definition	References
Top management commitment, $C_{1,1}$	It may be defined as the direct participation of the highest level executives in a specific and critically important aspect or program of an enterprise from the prospective of establishing quality policies and objectives in enterprises.	[Source: http://www.businessdictionary.com/definition/top-management-commitment.html]
Middle management commitment, $C_{1,2}$	It is the liability of middle level manager to compliance the commitment of top management and successful implementation those commitment (policy, initiatives, and workforce) throughout the enterprises.	[Source: http://csqa.blogspot.in/2006/11/kc-211-executive-and-middle-management.html]
Cross functional cooperation, $C_{1,3}$	It is the cooperation of group employees of different functional expertise to work upon a specific objective/ goal for the enterprise.	[Source: http://en.wikipedia.org/wiki/Cross-functional_team]
Employee involvement, $C_{1,4}$	Creating an environment in which people have an impact on decisions and actions that affect their jobs. It is a management and leadership philosophy about how people are most enabled to contribute towards continuous improvement and the ongoing success of their work organization.	[Source: http://humanresources.about.com/od/glossarye/a/employee_inv.htm]
Design of products for reduced consumption of material/energy, $C_{2,1}$	It is the process of creating a design of new product from the prospectus of reducing or minimizing the energy and material consumption level.	[Source: http://en.wikipedia.org/wiki/Product_design]
Design of products for reuse, recycle, recovery of material, component parts, $C_{2,2}$	It stands for creating a design of a new product from the aspects of reuse, recycle, recovery of material after employed or explored by consumer.	[Source: http://www.all-recycling-facts.com/what-is-recycling.html]
Design of products to avoid or reduce use of hazardous products and/or their manufacturing process, $C_{2,3}$	It stands for creating a design of a new product in such a manner that can incorporate to avoid or reduce use of hazardous products and/or their manufacturing process.	[Source: http://navyadvancement.tpub.com/14504/css/14504_105.htm]
Green purchasing, $C_{3,1}$	Buying products that are sourced and/or manufactured in an environmentally friendly way. Green Purchasing is the method wherein environmental and social considerations are taken with equal weight to the price, availability and performance criteria used to make purchasing decisions.	[Source: http://www.trinity.edu/departments/purchasing/green%20purchasing%20definition.htm, www.tameside.gov.uk/la21/glossary]
Green marketing, $C_{3,2}$	Green marketing is the marketing mode which considers ecological aspects and requires an enterprise to meet demand from both consumer satisfaction and environmental protection perceptive.	
Investment recovery, $C_{3,3}$	It is a systematic, centralized organizational effort to manage the surplus/obsolete equipment/material and scrap recovery/marketing/disposition activities in a manner that recovers as much of the original capital investment as possible.	[Source: http://www.ism.ws/tools/content.cfm?ItemNumber=4469]
Environmental process, $C_{3,4}$	Those processes, actions, operations, and cycles that occur naturally in the environment without the intervention or aid of man. This framework element serves as a broad placeholder for all	[Source: http://www.hq.nasa.gov/iwgsdi/Environmental_Processes.html]

	natural processes.	
Business ethics, $C_{4,1}$	It is also known as corporate ethics. It examines ethical principles and moral or ethical problems that arise in a business environment.	[Source: http://en.wikipedia.org/wiki/Business_ethics]
CSR activities, $C_{4,2}$	It means corporate social responsibility which is the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large.	[Source: http://www.mallenbaker.net/csr/definition.php]
Employment generation, $C_{4,3}$	It is the assessment of assisting unemployed members in an organization from the aspect of carrying out the prescribed task to the completion.	[Source: http://en.wikipedia.org/wiki/Employment_creation]
Environmental performance, $C_{5,1}$	It is the relationship between the organization and the environment. It includes: the environmental effects of resources consumed, the environmental impacts of the organizational process, the environmental implications of its products and services, the recovery and processing of products.	[Source: http://www.encyclo.co.uk/define/Environmental%20Performance]
Economic performance, $C_{5,2}$	It is an assessment for an organization of its success in areas related to its assets, liabilities and overall market strength. Many business operators take regular stock on either a formal or less formal basis of the general economic performance of their company to make sure that it remains on the right track financially.	[Source: http://www.businessdictionary.com/definition/economic-performance.html]
Operational performance, $C_{5,3}$	It is the measurement of enterprises performance against standard or prescribed indicators of effectiveness, efficiency, and environmental responsibility such as, cycle time, productivity, waste reduction, and regulatory compliance.	[Source: http://www.businessdictionary.com/definition/operational-performance.html]

Definitions of Green Supply Chain Performance Metrics (3rd level indices)

Metric (3rd level)	Definition	References
Providing design specification to suppliers with environmental requirements, $C_{3,11}$	It is the intimation to the supplier/partner regarding the acquisition of specific product along with reported specifications under the favorable environmental condition.	[Source: http://www.madebydelta.com/delta/Business_units/TC/Services+by+technology/Reliability/Specification+of+environmental+conditions.page]
Cooperation with suppliers to environmental objectives, $C_{3,12}$	It is an innovative partnership amongst product manufacturing organization and their partner and the Environmental Protection Agency (EPA) which improves and maintains green sustainability performance.	[Source: http://www.supplierspartnership.org/]
Environmental audit for supplier internal management, $C_{3,13}$	It is a management tool comprising a systematic, documented, periodic and objective evaluation of the performance of the supplier. It ensures an efficient supplier internal management	[Source: http://www.snh.org.uk/publications/on-line/advisorynotes/45/45.htm]

	system and processes designed to protect the environment.	
Supplier ISO 14000 certification, $C_{3,14}$	This certification is a standard which ensures that supplier is dealing with environmental issues such as reducing raw material use, reduce energy consumption, improve efficiency and reduce waste.	[Source: http://www.thomasnet.com/certifications/glossary/quality-certifications/iso/iso-14000/]
Second tier supplier environmental friendly practices evaluation, $C_{3,15}$	It is an evaluation of sustainability practices (measure, metrics) for selecting the second tier supplier at the condition while primitive supplier or partner become unable to deliver enough quantity to an organization because of some own specific reason.	[Source: Gullo and Kalt, 2010]
Cooperation with customer for eco -design, $C_{3,21}$	It is an approach to produce customer-oriented products design concerned along with ecological (sustainability) aspects which leverages minimum or zero environmental impact during its whole life cycle of product, from beginning; procurement, manufacture to use and disposal end.	[Sources: http://en.wikipedia.org/wiki/Eco-design and [Sources: www.hoganas.com/.../NAH/Powder_NewsSanDiego1_2006_NAH.pdf]
Cooperation with customer for cleaner production, $C_{3,22}$	It is a continual application of waste minimization and prevention practices during manufacturing of product. It associates practices such as conservation of raw materials and energy, elimination of toxic inputs, and reduction in toxic outputs.	[Sources: http://www.businessdictionary.com/definition/cleaner-production.html]
Cooperation with customer for green packaging, $C_{3,23}$	It is the development and usage of product packaging in the way of customer desirability in order to improve and maintain the sustainability (ecological balance).	[Sources: http://en.wikipedia.org/wiki/Green_packaging]
Cooperation with customer for least energy consumption for logistics, $C_{3,24}$	It is the management of the flow of resources between the points of origin to point of consumption in order to meet customer demand. It is called corporations with customers in logistic environment. So, least energy consumption in logistics is defined as minimizing or reducing energy consumption of resources from the point of origin to point of consumption in logistic supply chain activities.	[Sources: http://en.wikipedia.org/wiki/Logistics]
Investment recovery of excess inventory, $C_{3,31}$	It is the process of recouping or re-clutching the value of unused (excess inventory) through effective reuse or divestment.	[Source: http://www.epiqtech.com/investment-recovery.htm]
Sales of scrap and used materials, $C_{3,32}$	It is a sale or inviting tenders for the used/scrap materials to be sold either through advertised tenders or giving tender inquiries to likely purchasers.	[Source: http://www.nfr.railnet.gov.in/store/read/ch12.htm]
Sales of excess capital equipment, $C_{3,33}$	It is the amount by which the proceeds from the sale of excess equipment (that had been used in the business) exceeded its carrying amount at the time it is sold.	[Source: http://www.accountingcoach.com/terms/G/gain-on-sale-of-equipment.html]
Environmental compliance and audit procedure, $C_{3,41}$	Environmental compliance is the obeying of environmental policy, rule and legislation by organization and environmental audit procedure. It is a management tool comprising a systematic,	[Source: http://www.snh.org.uk/publications/on-line/advisorynotes/45/45.htm]

	documented, periodic and objective evaluation of the performance of the organization, management system and processes designed to protect the environment.	
ISO 14000 certification, $C_{3,42}$	It provides practical tools for companies and organizations looking to identify and control their environmental impact and constantly improve their environmental performance.	[Sources: http://www.iso.org/iso/home/standards/managementstandards/iso14000.htm]
Environmental management system, $C_{3,43}$	It is a framework that helps a company to achieve its environmental goals through consistent control of its operations. It also improves the environmental performance of the company.	[Sources: http://www.epa.gov/ems/]
Eco leveling of products, $C_{3,44}$	It encompasses a new idea to identify and promote labeling of products or packaging that has reduced adverse environmental (sustainability) impact.	[Source: http://www.pca.org.au/site/cms/documents/issues/issues12.html]
Reduction of emission, $C_{5,11}$	It is the reduction in environmental emissions-substances that are released into the air as waste. Many times, these emissions are the result of combustion, manufacturing, and natural waste.	[Source: http://www.wisegeek.com/what-are-environmental-emissions.htm]
Reduction of usage of harmful materials, $C_{5,12}$	It may be defined as a reduction or minimization of an usage of those substances that are ignitable (flammable), corrosive, toxic, explosive, or reactive, i.e., react with air, water, or acids or bases.	[Source: http://ehs.utah.edu/research-safety/chemical-safety/hazardous-materials-and-waste/hazardous-materials-definitions]
Reduction of accidents, $C_{5,13}$	It is a comparatively rare but often catastrophic event that occurs within complex modern organization, these involving multiple causes involving several employees operating at different levels in companies. These accidents can have devastating effects on uninvolved populations, assets and the environment.	
Recycling of materials, $C_{5,14}$	It may be defined as an exploration; usage and re-processing of employed or waste stuff, unwanted material/scrap, and recovered goods.	[Source: http://www.reman.org/aboutreman_main.htm]
Sale of art design for reverse logistics, $C_{5,15}$	Reverse logistic associates all activity from point of consumption to point of origin. So, sale of art design for reverse logistics is the art to design a re-used good with the amendment of modified features which can have ability in order to meet of the consumer demand.	[Source: Rogers and Tibben-Lembeko, (1998)]
Energy consumption, $C_{5,21}$	It is an amount of energy consumed in a process or production by an organization from the prospectus of product manufacturing.	[Source: http://www.businessdictionary.com/definition/energy-consumption.html]
Cost of procurement, $C_{5,22}$	It is the acquisition of goods, services or works from an external source. The cost associated with goods, services or works procured to meet the needs of the customer in terms of quality and quantity, time, and location.	[Source: http://en.wikipedia.org/wiki/Procurement]
Water usage, $C_{5,23}$	It may be defined as an amount of water explored by enterprises in order to complete the scheduled production of a prescribed	[Source: http://en.wikipedia.org/wiki/Water_use]

	quantity of some product.	
Reduction of disposal cost, $C_{5,24}$	The cost associated with amount of money incurred for the action of removing or getting rid of refuse or unwanted materials left over from a manufacturing process.	[Source: http://www.eionet.europa.eu/gemet/concept?ns=1&cp=9065]
Reduction of waste, $C_{5,25}$	Waste reduction involves an effort to minimize and reduce the waste or scrap from the point of origin to point of customer delivery.	[Source: http://en.wikipedia.org/wiki/Waste_minimisation]
Optimum design, $C_{5,31}$	It is the manner in which a management optimally design the combination of miscellaneous and integrated organization's operations in response to the level of uncertainty in its external environment.	[Source: http://www.businessdictionary.com/definition/organizational-design.html]
Minimum inventory, $C_{5,32}$	It may be defined as the control limit in a stock control system that indicates at which point a replenishment order should be placed to avoid depleting the safety stock.	[Source: http://www.businessdictionary.com/definition/minimum-inventory.html]
Capacity utilization, $C_{5,33}$	It refers to the extent to which an enterprise or a nation actually usage its installed productive capacity. Capacity utilization improvement is the incensement in its installed productive capacity.	[Source: http://en.wikipedia.org/wiki/Capacity_utilization]
Improved quality, $C_{5,34}$	Improvement of quality is a formal approach to the analysis of performance and systematic efforts to create a positive image of the organization.	[Source: http://patientsafetyed.duhs.duke.edu/module_a/introduction/introduction.html]
Effective reverse logistics, $C_{5,35}$	It is the effective responses of flow surplus or unwanted material, goods, or equipment, through its logistics chain, for reuse, recycling, or disposal.	[Source: http://www.businessdictionary.com/definition/reverse-logistics.html]
Reduction of time for recycling, $C_{5,36}$	It states the reduction or minimization of time which span to usage the recycled material from the prospectus of re-manufacturing the goods.	[Source: http://cei.org/op-eds-and-articles/time-recycle-recycling]

CHAPTER 4

GREEN SUPPLIER SELECTION

4.1 Coverage

An integrated hierarchical evaluation platform (associated with 'green' performance indices) has been adapted towards evaluation and selection of alternative suppliers under green supply chain (GSC) philosophy. In this context, incompleteness, vagueness, imprecision, as well as inconsistency associated with subjective evaluation information aligned with ill-defined suppliers' assessment indices has been tackled through logical exploration of fuzzy set theory. A fuzzy based Multi-Level Multi Criterion Decision Making (FMLMCDM) approach as proposed by (Chu and Varma, 2012), has been case empirically studied in the context of green suppliers selection. Result obtained thereof, has been compared to that of Fuzzy-TOPSIS to validate application potential of the aforementioned FMLMCDM approach.

4.2 Problem Definition

Supplier selection is one of the fundamental issues associated in supply chain management as it contributes significantly to overall supply chain performance extent. A large and growing body of literature to supplier evaluation and selection exists. In recent years, an increasing environmental awareness has favored the emergence of the new green supply chain paradigm (Genovese et al., 2013). In green supply chain management (GSCM), an organization's environmental performance is mostly affected by its suppliers' environmental performance, and selecting green suppliers is a key strategic consideration in order to be more competitive in today's global market (Kannan et al., 2013). In GSCM decision making, approaches for evaluating green supplier performance must use both qualitative and quantitative environmental data (Govindan et al., 2013). However, such decision making is problematic due to the need of considering tangible and intangible factors both, which cause vagueness, ambiguity and complexity (Yücel and Güneri 2011). At the same time, the vagueness of the information in this type of problem makes decision making more complicated (Yang 2010). Consequently, many researchers realized the application potential of fuzzy set theory (FST) as offering an efficient mean of handling this uncertainty effectively and of converting human judgments into meaningful results (Yang, 2010; Yücel and Güneri, 2011; Zadeh, 1965).

This paper adopts the Fuzzy Multi-Level Multi-Criteria Decision Making (FMLMCDM) approach as proposed by (Chu and Varma, 2012) in evaluating green suppliers; here, criteria have been considered only qualitative (subjective) in nature. A hierarchical structure has been mathematically explored to depict the multiple levels multiple criteria and computation formulas have been clearly reported. Ratings of suppliers versus qualitative criteria and the importance weights of all the criteria have been assessed through linguistic values represented by fuzzy numbers. However, when there is more than one level in the criteria hierarchy, the multiplication of more than three fuzzy numbers will be encountered. As pointed out by (Chu and Velásquez, 2009; Chu and Varma, 2012), currently there no such solution is readily available to produce the membership function for the multiplication of more than three fuzzy numbers. The best way to resolve the above limitations may be to defuzzify all the fuzzy numbers before applying them to the suggested model. Thus, a proper defuzzification method is indeed necessary. Chu and Varma (2012) suggested the method of center of area (COA) to rank fuzzy numbers due to its simplicity of implementation. The concept of COA defuzzification could be found in Tong (1978) as early as 1978. Motivated by the work by (Chu and Varma, 2012), herein, formulae for COA in defuzzifying triangular fuzzy numbers have been adapted for the purpose of defuzzifying fuzzy numbers (Fig. 4.1-4.3, Eqs. 4.2-4.4). Ratings of suppliers versus qualitative criteria and the importance weights of all the criteria have been assessed in linguistic values represented by triangular fuzzy numbers. These fuzzy numbers have been defuzzified by the ranking approach of COA before they have been explored to the model. The final evaluation value of each supplier could be obtained by additive weighted ratings based on back propagation from the last to the first level in the hierarchical structure. Decision could then be made based on the evaluation values, the larger the value the better the performance. The ranking order of candidate green suppliers has been compared to that of Fuzzy-TOPSIS.

4.3 Fuzzy Set Theory

As computational part of the current work explores a fuzzy based MLMCDM approach in comparison with Fuzzy-TOPSIS; clear understanding on basics of fuzzy numbers set theory, fuzzy mathematics in combination with MLMCDM approach and elements of TOPSIS is indeed required. Hence, the following sections deal with theories of fuzzy sets, definition of fuzzy numbers, linguistic values, defuzzification formula, FMLMCDM model, and Fuzzy-TOPSIS.

4.3.1 Fuzzy Sets

A fuzzy set A can be denoted by $A = \{(x, f_A(x)) | x \in U\}$, where U is the universe of discourse, x is an element in U, A is a fuzzy set in U, $f_A(x)$ is the membership function of A at x (Kaufmann and Gupta, 1991). The larger $f_A(x)$, the stronger the grade of membership for x in A.

4.3.2 Fuzzy Numbers

A real fuzzy number A is described as any fuzzy subset of the real line R with membership function f_A which possesses the following properties (Dubois and Prade, 1978):

(a) f_A is a continuous mapping from R to $[0,1]$;

(b) $f_A(x) = 0, \forall x \in (-\infty, a|$;

(c) f_A is strictly increasing on $[a, b]$;

(d) $f_A(x) = 1, x \in [b, c]$;

(e) f_A is strictly deceasing on $[c, d]$;

(f) $f_A = 0, \forall x \in |d, \infty)$;

Here a, b, c, d are real numbers. We may let $a = -\infty$, or $a = b$, or $b = c$, or $c = d$, or $d = +\infty$.

Unless elsewhere specified, it is assumed that A is convex, normal and bounded, i.e. $-\infty < a, d < \infty$. For convenience, fuzzy number A can be denoted by $A = [a, b, c, d]$. The opposite of A can be given by $-A = [-d, -c, -b, -a; 1]\ x$ (Kaufmann and Gupta, 1991). Fuzzy number A is a triangular fuzzy number, denoted by (a, b, c), if; its membership function f_A is given by (van Laarhoven and Pedrycz, 1983):

$$f_A(x) = \begin{cases} (x-a)/(b-a), & a \le x \le b, \\ (x-c)/(b-c), & b \le x \le c, \\ 0, & Otherwise. \end{cases} \tag{4.1}$$

4.3.3 Linguistic Values

A linguistic variable is a variable whose values are expressed in linguistic terms. Linguistic variable is a very helpful concept for dealing with situations which are too complex or not well-defined to be reasonably described by traditional quantitative expressions (Zadeh, 1975; 1976). It is assumed that decision makers have fully understood the meanings of these linguistic values and their corresponding fuzzy numbers before they assign these values to criteria.

4.3.4 Defuzzifying triangular fuzzy numbers with COA

The following formulas are developed to defuzzify triangular fuzzy numbers based on deviding the area under the membership function in half. The defuzzification formulas for fuzzy number A in Eq. 4.1 by using COA, i.e. $I_L(A) = I_R(A)$, are presented in the following three situations:

(a) If $\overline{ab} > \overline{bc}$ as shown in Fig. 4.1:

Thus, according to Fig. 4.1, e is derived from "$I_L(A) = I_R(A)$" as

$$e = a + \frac{1}{2}\left[2a^2 - 2ab - 2ac + 2bc\right]^{\frac{1}{2}} \tag{4.2}$$

(b) If $\overline{ab} < \overline{bc}$ as shown in Fig. 4.2:

Thus, according to Fig. 4.2, e is derived from "$I_L(A) = I_R(A)$" as

$$e = c - \frac{1}{2}\left[2c^2 + 2ab - 2ac - 2bc\right]^{\frac{1}{2}} \tag{4.3}$$

(c) If $\overline{ab} = \overline{bc}$ as shown in Fig. 4.3:

According to Fig. 4.3, the defuzzification value e equals to b. Thus, e is derived from "$I_L(A) = I_R(A)$" as

$$e = \frac{1}{2}(a + c) \tag{4.4}$$

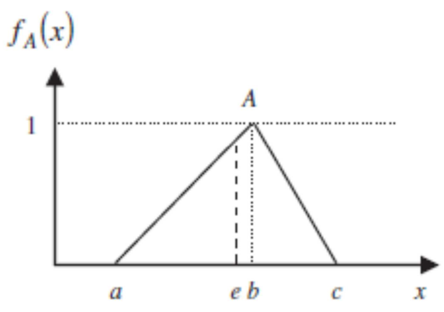

Fig. 4.1: Triangular Fuzzy Number A and its defuzzification value e

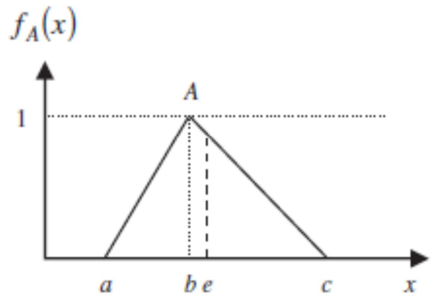

Fig. 4.2: Triangular Fuzzy Number A and its defuzzification value e

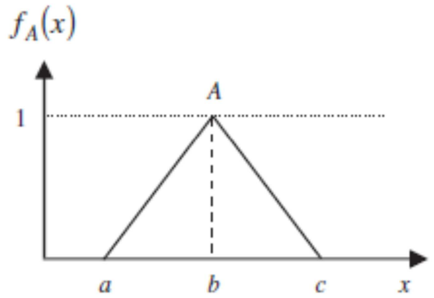

Fig. 4.3: Triangular Fuzzy Number A and its defuzzification value e

4.4 Model Development

4.4.1 Notations

Some important mathematical notations used in the proposed model are defined as follows:

D_v :Denotes decision maker $v, v = 1,...,q;$

A_i :Denotes fuzzy numbers used to evaluate the importance of the importance of the criteria, $i = 1,...,n;$

B_i :Denotes fuzzy numbers used to evaluate the suitability of alternatives versus qualitative criteria, $i = 1,...,n;$

$e(A_i)$:Denotes the defuzzified value of A_i through COA;

$e(B_i)$:Denotes the defuzzified value of B_i through COA;

$f_{x_1 x_2 \ldots x_i \ldots x_n}$: Denotes the n level (general) hierarchy structure to depict the relationship amongst criteria;

$m_{x_1 x_2 \ldots x_{(i-1)}}$: Denotes number of sub-criteria for criterion $f_{x_1 x_2 \ldots x_i}$;

$w_{x_1 x_2 \ldots x_i v}$: Denotes the weight given by the v^{th} decision-maker to the $x_1 x_2 \ldots x_i{}^{th}$ criterion, $1 \leq v \leq q$;

W : Denotes vector;

M : Denotes matrix;

$r_{x_1 x_2 \ldots x_i t v}$: Denotes the suitability given by the v^{th} decision-maker to the $x_1 x_2 \ldots x_i{}^{th}$ criterion for alternative t;

$R_{m_{x_1 x_2 \ldots x_{(i-1)}} \times p}$: Denotes $m_{x_1 x_2 \ldots x_{(i-1)}} \times p$ matrix of the $m_{x_1 x_2 \ldots x_{(i-1)}}$ suitability values of sub-criteria of the criterion $f_{x_1 x_2 \ldots x_{(i-1)}}$ from p alternatives.

4.4.2 The MLMCDM Model

In this section, the proposed COA defuzzification method is applied to establish a MLMCDM (multiple levels multiple criteria decision making) model under fuzzy environment. Suppose the importance weights of different criteria and the ratings of various alternatives under qualitative criteria in the model are assessed in linguistic terms (Zadeh, 1975) represented by triangular fuzzy numbers. Further suppose a set of linguistic terms represented by positive triangular fuzzy numbers $A_i, i = 1,..,n,$ are applied by decision-makers D_v, $v = 1,...,q,$ to evaluate the importance of the criteria. Also a set of linguistic terms represented by positive triangular fuzzy numbers $B_i, i = 1,..,n,$ are applied by decision makers to evaluate the suitability of alternatives versus qualitative criteria. By applying (Eqs. 4.2-4.4), we obtain the values of COA of these fuzzy numbers as $e(A_i)$ and $e(B_i)$, respectively. The proposed model is developed by the following procedure.

Establish a multiple levels hierarchy structure for criteria

A general hierarchical structure to depict criteria is presented as follows:

$$F_{x_i} = \{ f_{x_1 x_2 \ldots x_i \ldots x_n} \} \tag{4.5}$$

For example, f_{x_1} represents the first level criteria of evaluated alternatives, $f_{x_1x_2}$ represents second level criteria of f_{x_1}, and the number of the second level criteria is m_{x_1}. Herein, the criteria in the hierarchical structure are assumed to be independent (Table 4.1).

Decide the weights

When decision makers assign weights to criteria, they must understand the meanings of the linguistic weights and their corresponding fuzzy numbers; in other words, we assume that decision makers' understanding of the concept of ''importance'' is in full compliance with the way that weights are used in the model.

The average weights associated with n level hierarchical structure are developed the following equation:

$$w_{x_1x_2...x_i} = \frac{1}{q}\left\{w_{x_1x_2...x_i1} + w_{x_1x_2...x_i2} + ... + w_{x_1x_2...x_iv} + ... + w_{x_1x_2...x_iq}\right\} \quad (4.6)$$

Here $w_{x_1x_2...x_iv}$ is a defuzzified triangular fuzzy number from $e(A_i)$. Also $w_{x_1x_2...x_i}$ represents the weight of criterion $f_{x_1x_2...x_i}$.

Average alternative suitability versus qualitative criteria

The average suitability of alternative t, $t = 1,..., p$, versus each subjective criterion associated with n level hierarchy structure is presented as follows:

$$r_{x_1x_2...x_it} = \frac{1}{q}\left\{r_{x_1x_2...x_it1} + r_{x_1x_2...x_it2} + ... + r_{x_1x_2...x_itv} + ... + r_{x_1x_2...x_itq}\right\} \quad (4.7)$$

Here $r_{x_1x_2...x_itv}$ is a defuzzified triangular fuzzy number from $e(B_i)$ and $r_{x_1x_2...x_it}$ represents the average suitability of alternative t versus criterion $f_{x_1x_2...x_i}$.

Normalization of alternative suitability versus qualitative criteria

Values (or suitability) of alternatives versus different quantitative criteria need to be normalized because they have different units. If only benefit (or cost) qualitative criteria are used, normalization can be omitted. In this model, suitability of alternatives versus quantitative criteria can be classified into benefit (B) and cost (C) ones. The normalization of the suitability can be accomplished by applying the following two formulas:

$$r_{x_1x_2\ldots x_it}=\frac{S_{x_1x_2\ldots x_it}}{\max_t\{S_{x_1x_2\ldots x_it}\}}, \tag{4.8}$$

$$r_{x_1x_2\ldots x_it}=\frac{\min_t\{S_{x_1x_2\ldots x_it}\}}{S_{x_1x_2\ldots x_it}}. \tag{4.9}$$

Here $r_{x_1x_2\ldots x_it}$ denotes the normalized value of $S_{x_1x_2\ldots x_it}$. Also $S_{x_1x_2\ldots x_it}$ denotes the suitability value of alternative t versus criterion $f_{x_1x_2\ldots x_i}$.

Synthetic evaluation

The additive weighted evaluation matrices in the structure can be obtained by using multiplication and addition to aggregate the evaluation matrices and their corresponding weights matrices as follows:

$$M_{x_1x_2\ldots x_{(i-1)}}=W_{x_1x_2\ldots x_{(i-1)}}\times R_{m_{x_1x_2\ldots x_{(i-1)}}\times p}$$
$$=\left[\sum_{x_i=1}^{m_{x_1x_2\ldots x_{(i-1)}}} w_{x_1x_2\ldots x_i}.r_{x_1x_2\ldots x_i1}\ \sum_{x_i=1}^{m_{x_1x_2\ldots x_{(i-1)}}} w_{x_1x_2\ldots x_i}.r_{x_1x_2\ldots x_i2}\cdots \sum_{x_i=1}^{m_{x_1x_2\ldots x_{(i-1)}}} w_{x_1x_2\ldots x_i}.r_{x_1x_2\ldots x_it}\cdots \sum_{x_i=1}^{m_{x_1x_2\ldots x_{(i-1)}}} w_{x_1x_2\ldots x_i}.r_{x_1x_2\ldots x_ip}\right]$$
$$=\left\lfloor r_{x_1x_2\ldots x_{(i-1)}1} r_{x_1x_2\ldots x_{(i-1)}2}\ldots r_{x_1x_2\ldots x_{(i-1)}t}\ldots r_{x_1x_2\ldots x_{(i-1)}p}\right\rfloor \tag{4.10}$$

Here $M_{x_1x_2\ldots x_{(i-1)}}$ is a $1\times p$ vector with the additive weighted evaluations of the p alternatives over the criteria set $f_{x_1x_2\ldots x_i}$, $W_{x_1x_2\ldots x_{(i-1)}}$ is the vector of the corresponding criteria weights and $R_{m_{x_1x_2\ldots x_{(i-1)}}\times p}$ is a matrix with the suitability of the alternatives on the criteria. $w_{x_1x_2\ldots x_{(i-1)}}$ is derived by Eq. 4.6, t represents alternative t. $r_{x_1x_2\ldots x_it}$ is defined from Eq. 4.7, when $f_{x_1x_2\ldots x_i}$ is a qualitative criterion with no sub-criteria, from Eq. 4.8 and Eq. 4.9 when $f_{x_1x_2\ldots x_i}$ is a quantitative criterion with no sub-criteria, or from $\sum_{x_{(i+1)}=1}^{m_{x_1x_2\ldots x_i}} w_{x_1x_2\ldots x_{(i+1)}}.r_{x_1x_2\ldots x_{(i+1)}t}$ when $f_{x_1x_2\ldots x_i}$ is not further analyzed into lower-level sub-criteria. $\sum_{x_i=1}^{m_{x_1x_2\ldots x_{(i-1)}}} w_{x_1x_2\ldots x_i}.r_{x_1x_2\ldots x_it}$ denotes the additive weighted evaluation value, $r_{x_1x_2\ldots x_{(i-1)}t}$, of sub-criterion $f_{x_1x_2\ldots x_{(i-1)}}$ of $f_{x_1x_2\ldots x_{(i-2)}}$ from alternative t, and is the corresponding element of the $x_{(i-1)}th$ row and the t^{th} column in $R_{m_{x_1x_2\ldots x_{(i-2)}}\times p}$. The aggregation at every level of the hierarchy is done similarly to Eq. 4.10.

Table 4.1: The 4-level general hierarchical structure of criteria

Goal	1st level criteria	2nd level criteria	3rd level criteria	4th level criteria
Green supplier evaluation and selection	f_1	f_{11}	f_{111}	f_{1111}
				f_{1112}
				f_{1113}
			f_{112}	f_{1121}
				f_{1122}
				f_{1123}
				f_{1124}
		f_{12}	f_{121}	f_{1211}
				f_{1212}
				f_{1213}
				f_{1214}
			f_{122}	f_{1221}
				f_{1222}
		f_{13}	f_{131}	f_{1311}
				f_{1312}
			f_{132}	f_{1321}
	f_2	f_{21}	f_{211}	f_{2111}
				f_{2112}
			f_{212}	f_{2121}
			f_{213}	f_{2131}
			f_{214}	f_{2141}
				f_{2142}
			f_{215}	f_{2151}
				f_{2152}
			f_{216}	f_{2161}
				f_{2162}
		f_{22}	f_{221}	f_{2211}
			f_{222}	f_{2221}

The final additive weighted evaluation matrix can then be derived by Eq. 4.10 based on the rule of back propagation as follows:

$$M = W \times R_{m \times p} = \left[\sum_{x_1=1}^{m} w_{x_1}.r_{x_1 1} \sum_{x_1=1}^{m} w_{x_1}.r_{x_1 2} \ldots \sum_{x_1=1}^{m} w_{x_1}.r_{x_1 t} \ldots \sum_{x_1=1}^{m} w_{x_1}.r_{x_1 p} \right] = \left[r_1 r_2 \ldots r_t \ldots r_p \right] \quad (4.11)$$

Here M represents the set of final additive weighted evaluation of all the m major criteria from p alternatives, and is the $1 \times p$ evaluation matrix. Here $R_{m \times p}$ represents a $m \times p$ matrix. Also w_{x_1} and $r_{x_1 t}$ are the corresponding elements in W and $R_{m \times p}$, respectively. w_{x_1} is derived by Eq. 4.6. Now, $r_{x_1 t}$ is derived from Eq. 4.7, when f_{x_1} is a qualitative criterion with no sub-criteria, from (Eqs. 4.8-4.9), when f_{x_1} is a quantitative criterion with no sub-criteria, or from $\sum_{x_2=1}^{m_{x_1}} w_{x_1 x_2}.r_{x_1 x_2 t}$ when f_{x_1} is not further analyzed into lower-level sub-criteria. Also $\sum_{x_1=1}^{m} w_{x_1}.r_{x_1 t}$ denotes the final additive weighted evaluation value, r_t, of the major criterion f_{x_1} from alternative t. The better performance the alternative, the higher the evaluation value; therefore the alternative that has the highest evaluation value should be chosen.

4.5 Fuzzy-TOPSIS

The procedural steps of Fuzzy-TOPSIS using triangular fuzzy numbers have been presented below (Ding, 2011; Liao and Kao, 2011; Halder et al., 2014).

Step 1: A fuzzy multi-criteria group decision making problem can be concisely expressed in matrix format as $\tilde{\mathbf{X}} = \left[\tilde{x}_{ij}\right]_{m \times n}$ with the weight vector $\tilde{\mathbf{W}} = \left[\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n\right]$

The importance weight of each criterion can be obtained by assigning either directly or indirectly using pairwise comparisons. Decision-Makers use the linguistic variables shown in Table 4.3 to evaluate the importance of the criteria and the ratings of alternatives with respect to various criteria. Assume that a decision group has K persons, and the importance of the criteria and the ratings of alternatives with respect to each criterion can be calculated as:

$$\tilde{x}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)\ldots(+)\tilde{x}_{ij}^{K}\right] \quad (4.12)$$

$$\tilde{w}_j = \frac{1}{K}\left[\tilde{w}_j^1(+)\tilde{w}_j^2(+)...(+)\tilde{w}_j^K\right] \quad (4.13)$$

Here $\tilde{x}_{ij}^K$ and $\tilde{w}_j^K$ are, respectively, the aggregated ratings of alternatives and the aggregated ratings of the importance weight of the k^{th} decision-maker, and $(+)$ indicates the fuzzy arithmetic summation function.

Step 2: The normalized decision matrix is formed using Eqs. 4.14-4.17. In order to avoid the complicated normalization formula used in classical TOPSIS, in some papers a linear scale transformation is used to transform the various criteria scales into a comparable scale. Thereby, it is possible to obtain the normalized fuzzy decision matrix denoted by $\tilde{\mathbf{R}}$.

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n}$$

Here B and C are the set of benefit criteria and cost criteria, respectively, and

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \quad j \in B, \quad (4.14)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad j \in C, \quad (4.15)$$

$$c_j^* = \max_i c_{ij}, \quad If \quad j \in B, \quad (4.16)$$

$$a_j^- = \min_i a_{ij}, \quad If \quad j \in C. \quad (4.17)$$

Step 3: Now the weighted normalized decision matrix is formed using Eqs. 4.18 -4.19:

$$\tilde{\mathbf{V}} = \left[\tilde{v}_{ij}\right]_{m\times n}, \quad i = 1,2,...,n, \quad (4.18)$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_{ij} \quad (4.19)$$

Step 4: Sorting of the positive ideal solution A^+ and the negative ideal solution A^- are determined using Eqs. 4.20-4.21.

$$A^+ = \left(\tilde{v}_1^+, \tilde{v}_2^+, ..., \tilde{v}_n^+\right), \quad (4.20)$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-\right). \quad (4.21)$$

Step 4: Calculation of the separation measure.

Calculate the distance of each alternative from the positive ideal solution and the negative ideal solution (Eq. 4.23-4.24). This has been computed according to (Dalah et al., 2011), the distance between two triangular fuzzy numbers $\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$ is calculated using Eq. (4.22), as

$$d\left(\tilde{A}_1, \tilde{A}_2\right) = \sqrt{\frac{\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\right]}{3}} \tag{4.22}$$

$$d_i^+ = \sum_{j=1}^{k} d\left(\tilde{v}_{ij}, v_j^+\right),\ i = 1,2,\ldots,m \tag{4.23}$$

$$d_i^- = \sum_{j=1}^{k} d\left(\tilde{v}_{ij}, v_j^-\right),\ i = 1,2,\ldots,m. \tag{4.24}$$

Step 6: The closeness coefficient (CC_i) for each of the supplier alternatives is determined using Eq. (4.25):

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+},\ i = 1,2,\ldots m. \tag{4.25}$$

4.6 Case Empirical Research

In the present reporting, a double-layer hierarchical green supplier evaluation platform has been adapted as depicted in Table 4.2. It has been aimed to evaluate (select) and benchmark suppliers' performance in view of three candidate green suppliers such as A_1, A_2, A_3. The appraisement platform i.e. multi-level evaluation platforms have been chosen from the knowledge of past literature (Kuo et al., 2010; Yeh and Chuang, 2011; Humphreys, 2003) and case empirically studied.

Hereby, the double-layer evaluation index system (Table 4.2) assumed consists of several subjective (qualitative) green supplier evaluation indices as well as sub-indices (at Level 1 and 2, respectively) which encompasses several beneficial attributes/criteria. Management competencies (C_1), 'Green image' (C_2), Design for environment (C_3), Environmental management systems (C_4), and, Environmental competencies (C_5) has been considered at the 1st-level of the criteria hierarchy; all are beneficial in nature. Each 1st level index is followed a number of subjective sub-indices at 2nd level. The definitions (explanations) of various performance evaluation indices (that exist in double-layer hierarchy criteria) as have also been depicted in Table 4.2.

To facilitate evaluating importance grade (priority importance) of individual evaluation indices as well as appropriateness ratings (performance extent) of subjective evaluation indices at different levels; a committee of five Decision-Makers (DMs) (expert group) such as (DM_1, DM_2,…,DM_5) has been assumed constructed.

In this work, priority weights against individual evaluation indices and performance extent (appropriateness ratings) against subjective evaluation indices have been obtained through linguistic information as provided by the expert group. Linguistic human judgment has further been transformed into appropriate TFNs (Triangular Fuzzy Number set). Here, the set of linguistic variables for rating as well as weight assignment against individual performance indices has been expressed by fuzzy numbers (1-5 point scale) as pointed out in Table 4.3. The procedural steps of the entire evaluation as well as appraisement module to support green supplier selection followed by results of case illustration have been summarized as follows.

4.6.1 Case Illustration: Exploration of FMLMCDM Approach

Step 1: Gathering information from the expert group in relation to performance rating and importance weights of different evaluation indices using linguistic terms

In order to evaluate priority importance (weight) against individual 1st and 2nd level indices, as well as appropriateness rating against individual 2nd level indices; a committee of fives decision-makers (DMs), DM_1, DM_2, DM_3, DM_4, DM_5 has been formed to express their subjective preferences (evaluation score) in linguistic terms which have been further transformed into appropriate TFNs set (1-5 point scale) (Table 4.3). The following linguistic terms: Unsatisfactory (U), Poor (P), Medium (M), Satisfactory (S), and, Excellent (E) have been explored for assessing suitability of performance (rating) against individual 2nd level indices. Similarly, the linguistic terminology: Unimportant (UI), Slightly Important (SI), Fairly Important (FI), Important (I), and Very Important (VI) has been used for assigning priority weight of different evaluation indices.

The expert panel assessed the priority importance (weight) against individual 2nd level as well as 1st level performance indices and provided expert opinion in linguistic terms as depicted in Table 4.4 and Table 4.5, respectively. Also, the appropriateness rating (in linguistic terms) against individual 2nd level evaluation indices as assigned by the expert panel have been depicted in Tables 4.6-4.8, for alternative green suppliers A_1, A_2 and A_3, respectively.

Step 2: Approximation of the linguistic evaluation information by triangular fuzzy number set

Linguistic decision making information have been transformed into appropriate fuzzy numbers as per Table 4.3. By exploring the concept of Triangular Fuzzy Number (TFN) in fuzzy set theory,

fuzzy average rules (Eq. 4.6-4.7), aggregated fuzzy priority weight against individual 2nd as well as 1st level evaluation indices have been computed (Tables 4.4-4.5). Similarly, the aggregated fuzzy appropriateness rating against individual 2nd level evaluation indices (for preferred candidate alternatives A_1, A_2 and A_3) has been computed as depicted in Tables 4.6-4.8. Finally, aforesaid aggregated fuzzy scores (rating as well as weight) have been transformed in crisp score (defuzzification); results have been finished in (Tables 4.9-4.11). By following (Eq. 4.10), i.e. back propagating fuzzy rule, the appropriateness rating (crisp rating) against individual 1st level indices has been computed for preferred candidate alternatives A_1, A_2 and A_3 and revealed in Table 4.12.

Step 3: Construction of normalized as well as weighted normalized decision-making matrix

After constructing Table 4.12 (the decision making matrix), it is essential to normalize criteria values. (Eq. 4.8-4.9) have been explored and, finally, normalized rating (Table 4.13) has been multiplied with corresponding weights (crisp) against individual 1st level indices (Table 4.10) to evaluate the weighted normalized decision making matrix as depicted in (Table 4.14).

Step 4: Evaluation and selection of preferred alternative

After constructing the weighted normalized matrix, the ranking orders of preferred candidate alternatives has been determined by employing (Eq. 4.11). The ranking order appears to be A_3> A_2> A_1 (Table 4.15).

4.6.2 Case Illustration: Exploration of Fuzzy-TOPSIS

In this phase, Fuzzy-TOPSIS has been applied on the same supplier selection problem. The difference between FMLMCDM approach and Fuzzy-TOPSIS is that Fuzzy-TOPSIS explores a single level (a set of criteria) of evaluation criteria. Thus, data of a multi-level evaluation hierarchy must be transformed into a single level before applying Fuzzy-TOPSIS. This is done by following back propagation method and by exploring fuzzy weightage average rule

(Samantra et al., 2013). FMLMCDM explores defuzzified values (of fuzzy numbers) at every step of computation. On the contrary, Fuzzy-TOPSIS utilizes fuzzy operational rules. It determines a fuzzy positive-ideal and a fuzzy anti-ideal (negative ideal) solution. Then based on separation distance of each alternative with respect to fuzzy positive-ideal and fuzzy negative-ideal solution, a closeness coefficient is determined. Alternatives are then ranked in accordance with their closeness coefficient values. The computational steps of Fuzzy-TOPSIS have been described below.

Computed fuzzy multi-criteria group decision making (FMCGDM) matrix has been furnished in Table 4.16. This represents a set of criteria (at 1st level) C_1, C_2, C_3, C_4, C_5 and the alternatives A_1, A_2, A_3. This matrix has been obtained by utilizing aggregated fuzzy ratings of individual 2nd level criterions (and corresponding aggregated fuzzy weights) as shown in Tables 4.4, 4.6, 4.7, 4.8 for the preferred candidate alternatives. The fuzzy ratings of various 1st level criterions have been normalized fist (using Eq. 4.14). The normalized decision making matrix has been multiplied with corresponding priority weight of various 1st level criterions shown in Table 4.5. Table 4.17 represents the weighted normalized decision matrix. Fuzzy positive-ideal solution (A^+) and fuzzy negative-ideal solution (A^-) has been obtained using (Eqs. 4.20-4.21) and presented in Table 4.17. Distance (separation measures) of each alternative with respect to ideal as well as negative ideal solution have been obtained using (Eqs. 4.23- 4.24) and shown in Table 4.18. Based on d_i^+ as well as d_i^-, the closeness coefficient CC_i (i=1, 2, 3) of alternatives $\mathbf{A_1}$, $\mathbf{A_2}$ and $\mathbf{A_3}$ have been determined and shown in Table 18. The ranking order of candidate suppliers appear $A_3 > A_2 > A_1$, which appears same as obtained in FMLMCDM approach.

4.7 Managerial Implications

Today's business environment has forced industries to focus on effective supply chain management in order to gain competitive advantage. With the growing worldwide awareness of environmental protection and the corresponding increase in legislation and regulations, green supplier selection has become an important issue for companies to gain environmental sustainability. A firm's environmental performance is not only related to the firm's inner environmental efforts, but also it is greatly affected by the suppliers' environmental performance as well as 'green image'. During recent years, how to determine an appropriate supplier in the green supply chain construct has become a key strategic consideration. Apart from objective criteria there exist a number of subjective criteria to be taken under consideration while selecting a potential supplier in GSCM. Subjectivity of evaluation information often invites vagueness as well as ambiguity in the decision making and hence, exploration of fuzzy set theory may be proved fruitful. However, the choice of an efficient decision support module is of utmost important. To this end present work exhibits application potential of FMLMCDM approach in comparison with fuzzy-TOPSIS. Similar ranking order (for candidate suppliers) has been obtained from both FMLMCDM as well as Fuzzy-TOPSIS which indicates that both the methods are competent. However, working principles of FMLMCDM differs to that of Fuzzy-TOPSIS (Table 4.19). Industry management may explore these fuzzy based decision support modules in suitable circumstances to promote effective supplier selection considering green perspectives.

4.8 Concluding Remarks

Present study highlights application feasibility of fuzzy based MLMCDM module (in comparison with Fuzzy-TOPSIS) towards appraisement and selection of green suppliers in GSCM. The aforesaid FMLMCDM module is capable of working under multi-level integrated criteria hierarchy towards green supplier performance appraisement. It can further be extended to consider subjective as well as objective performance criterions both. Exploration of fuzzy set theory efficiently overcomes ambiguity as well as vagueness associated with subjective (linguistic) human judgment. Effectiveness of the said fuzzy embedded MLMCDM has been empirically tested in comparison with Fuzzy-TOPSIS and illustrated in detail for better understanding of the procedural steps as well as computational part of data analysis.

Table 4.2: Green supplier evaluation index system

1st Level indices; C_i	2nd level indices; C_{ij}	Definitions
Management competencies, C_1	Senior management support, C_{11}	Goals and objectives of green practices to be supported by the management for implementation.
	Environment partners, C_{12}	It is the relationship between supplier firm and its collaborative partners associated in green context.
	Training, C_{13}	It articulates the learning of best practices by employees for handling the specific task.
	Information exchange, C_{14}	The act of passing information from one firm to another, especially electronically, or a system.
Green Image, C_2	Customer's purchasing retention, C_{21}	To get past customers to purchase again.
	Green market share, C_{22}	It defines being hike or decline in the share value taking into account green reputation of the firm.
	Stakeholder's relationship, C_{23}	Stakeholder is the individual/group/organization that responds successfully towards delivery of project.
Design for environment, C_3	Recycle, C_{31}	It is a reuse of resources in an efficient way for reducing the cost of production and environmental pollution.
	Reuse, C_{32}	Reuse of an item or goods implies effective recovery of recycled material, energy and toxic emission from both initial material manufacture and manufacturing processes.
	Remanufacture, C_{33}	A worn out, defective, or discarded product are brought to disassemble stage.
	Disassembly, C_{34}	The disassembly is a process where individual product is being split up into its associated minor parts from repairement perspectives with negligible environmental impact.
	Minimal Disposal, C_{35}	It is final placement or riddance of wastes, excess, scrap, etc. under proper process and authority with no intention to retrieve.
Environmental management systems, C_4	Having environmental protection policies of suppliers, C_{41}	It refers to the adherence of green laws, regulations, and other policies/mechanisms towards environmental protection.
	Having environmental protection plans of suppliers, C_{42}	Planning to obey government green rules, legislation etc. by the supplier firm.
	Implement and operation, C_{43}	It articulates effective implementation and exploration of operational resources

		(technology, assesses and man-machine interaction) of supplier firm in green supply chain confine.
	Passing ISO 14000 verification of suppliers, C_{44}	ISO 14000 is a series of environmental management standards developed in support of organizations green performance. The ISO 14000 standards provide a guideline or framework for organizations that need to systematize and improve their environmental management efforts. Passing through the ISO 14000 verification assess the capability of the supplier firm to maintain considerable green performance.
Environmental competencies, C_5	Clean technology availability, C_{51}	It is defined as an elimination of unwanted energy sources and materials from point of origin to point of delivery (end users). Clean technology aligns recycling, renewable energy, information technology, green transportation, green chemistry, energy efficiency technologies, water technologies and green buildings etc.
	Use of environment friendly materials, C_{52}	It expresses the usage of those materials which are environment friendly.
	Pollution reduction capability, C_{53}	Capability to reduce waste creation and emission of pollutants released to land, air, and water without transferring pollutants from one medium to another.
	Returns handling capability, C_{54}	Capability of a firm to handle revert (complained/returned) goods/products in green supply chain architecture confines.

Table 4.3: Set of linguistic variables and corresponding fuzzy representation for assessing rating and priority weight against individual evaluation indices

Linguistic Term (Appropriateness Rating)	Corresponding Fuzzy Numbers	Linguistic Term (Priority Weights)	Corresponding Fuzzy Numbers
Unsatisfactory (U)	(0,0,0.25)	Unimportant (UI)	(0,0.1,0.3)
Poor (P)	(0,0.25,0.5)	Slightly Important (SI)	(0,0.2,0.5)
Medium (M)	(0.25,0.5,0.75)	Fairly Important (FI)	(0.3,0.45,0.7)
Satisfactory (S)	(0.5,0.75,1)	Important (I)	(0.5,0.7,0.8)
Excellent (E)	(0.75,1,1)	Very Important (VI)	(0.7,0.9,1)

Table 4.4: Priority weight (in linguistic term) as provided by DMs and corresponding aggregated fuzzy weight against individual 2nd level indices

C_{ij}	Priority weight (in linguistic term)					AFW $(Aggregated\ \ fuzzy\ \ weight)$
	DM_1	DM_2	DM_3	DM_4	DM_5	
C_{11}	I	VI	VI	VI	VI	(0.66,0.86,0.96)
C_{12}	VI	I	I	FI	FI	(0.46,0.64,0.80)
C_{13}	VI	FI	I	I	I	(0.50,0.69,0.82)
C_{14}	VI	FI	VI	I	FI	(0.50,0.68,0.84)
C_{21}	I	VI	VI	VI	VI	(0.66,0.86,0.96)
C_{22}	I	VI	VI	FI	VI	(0.58,0.77,0.90)
C_{23}	VI	VI	FI	FI	VI	(0.54,0.72,0.88)
C_{31}	VI	VI	VI	FI	SI	(0.48,0.67,0.84)
C_{32}	VI	VI	VI	FI	SI	(0.48,0.67,0.84)
C_{33}	VI	VI	VI	I	FI	(0.58,0.77,0.90)
C_{34}	VI	I	SI	I	VI	(0.48,0.68,0.82)
C_{35}	VI	FI	VI	I	VI	(0.58,0.77,0.90)
C_{41}	I	UI	FI	I	FI	(0.32,0.48,0.66)
C_{42}	I	UI	FI	I	FI	(0.32,0.48,0.66)
C_{43}	I	FI	FI	FI	FI	(0.34,0.50,0.72)
C_{44}	I	FI	FI	FI	SI	(0.28,0.45,0.68)
C_{51}	I	VI	FI	SI	SI	(0.30,0.49,0.70)
C_{52}	I	VI	FI	SI	VI	(0.44,0.63,0.80)
C_{53}	I	VI	I	SI	VI	(0.48,0.68,0.82)
C_{54}	I	VI	VI	I	VI	(0.62,0.82,0.92)

Table 4.5: Priority weight (in linguistic term) as provides by DMs and corresponding aggregated fuzzy weight against individual 1st level indices

C_i	Priority weight (in linguistic term)					$AFW\ (Aggregated\ \ fuzzy\ \ weight)$
	DM_1	DM_2	DM_3	DM_4	DM_5	
C_1	FI	I	I	FI	FI	(0.38,0.55,0.74)
C_2	FI	FI	FI	FI	FI	(0.30,0.45,0.70)
C_3	FI	VI	VI	SI	FI	(0.54,0.70,0.68)
C_4	FI	I	I	I	FI	(0.42,0.60,0.76)
C_5	I	I	I	SI	FI	(0.36,0.55,0.72)

Table 4.6: Appropriateness rating (in linguistic term) as provided by DMs and corresponding aggregated fuzzy rating against individual 2nd level indices for alternative **A_1**

C_{ij}	Appropriateness rating (in linguistic term)					$AFR\ (Aggregated\ \ fuzzy\ \ rating)$
	DM_1	DM_2	DM_3	DM_4	DM_5	
C_{11}	M	E	E	E	P	(0.50,0.75,0.85)
C_{12}	P	M	U	M	M	(0.15,0.35,0.60)
C_{13}	S	M	M	M	P	(0.25,0.50,0.75)
C_{14}	S	M	E	M	P	(0.35,0.60,0.80)
C_{21}	U	E	M	M	M	(0.30,0.50,0.70)
C_{22}	M	E	E	M	U	(0.40,0.60,0.75)
C_{23}	M	E	E	U	U	(0.35,0.50,0.65)
C_{31}	M	M	E	U	U	(0.25,0.40,0.60)
C_{32}	M	M	E	U	M	(0.30,0.50,0.70)
C_{33}	M	M	U	M	M	(0.20,0.40,0.65)

C_{34}	M	U	P	M	P	(0.10,0.30,0.55)
C_{35}	U	M	M	M	P	(0.15,0.35,0.60)
C_{41}	U	M	M	M	P	(0.15,0.35,0.60)
C_{42}	M	M	M	M	P	(0.20,0.45,0.70)
C_{43}	M	M	M	M	M	(0.25,0.50,0.75)
C_{44}	M	E	M	U	U	(0.25,0.40,0.60)
C_{51}	M	E	P	M	M	(0.30,0.55,0.75)
C_{52}	U	E	P	M	M	(0.25,0.45,0.65)
C_{53}	M	E	M	U	M	(0.30,0.50,0.70)
C_{54}	U	U	P	U	U	(0.00,0.05,0.30)

Table 4.7: Appropriateness rating (in linguistic term) as provided by DMs and corresponding aggregated fuzzy rating against individual 2nd level indices for alternative **A_2**

C_{ij}	$Appropriateness\ rating\ (in\ linguistic\ term)$					$AFR\ (Aggregated\ fuzzy\ rating)$
	DM_1	DM_2	DM_3	DM_4	DM_5	
C_{11}	U	E	E	E	E	(0.60,0.80,0.85)
C_{12}	E	U	U	M	E	(0.35,0.50,0.65)
C_{13}	E	U	M	M	E	(0.40,0.60,0.75)
C_{14}	E	M	U	E	E	(0.50,0.70,0.80)
C_{21}	M	E	U	E	M	(0.40,0.60,0.750
C_{22}	E	E	E	E	E	(0.75,1.00,1.00)
C_{23}	E	E	M	U	E	(0.50,0.70,0.80)
C_{31}	E	M	E	U	U	(0.35,0.50,0.65)
C_{32}	M	M	E	U	U	(0.25,0.40,0.60)

C_{33}	E	U	E	M	M	(0.40,0.60,0.75)
C_{34}	M	U	U	E	P	(0.20,0.35,0.55)
C_{35}	U	M	M	E	P	(0.25,0.45,0.65)
C_{41}	U	U	U	M	P	(0.05,0.15,0.40)
C_{42}	M	E	U	U	P	(0.20,0.35,0.55)
C_{43}	M	E	M	U	S	(0.35,0.55,0.75)
C_{44}	M	U	M	U	S	(0.20,0.35,0.60)
C_{51}	M	E	U	M	S	(0.35,0.55,0.75)
C_{52}	E	E	U	M	S	(0.45,0.65,0.80)
C_{53}	E	E	U	U	U	(0.30,0.40,0.55)
C_{54}	E	U	U	M	U	(0.20,0.30,0.50)

Table 4.8: Appropriateness rating (in linguistic term) as provided by DMs and corresponding aggregated fuzzy rating against individual 2nd level indices for alternative **A_3**

C_{ij}	$Appropriateness\ rating\ (in\ linguistic\ term)$					$AFR\ (Aggregated\ fuzzy\ rating)$
	DM_1	DM_2	DM_3	DM_4	DM_5	
C_{11}	S	E	E	E	P	(0.55,0.80,0.90)
C_{12}	S	M	U	M	M	(0.25,0.45,0.70)
C_{13}	U	M	M	M	M	(0.20,0.40,0.65)
C_{14}	S	E	E	E	P	(0.55,0.80,0.90)
C_{21}	U	E	M	E	M	(0.40,0.60,0.75)
C_{22}	U	E	M	E	E	(0.50,0.70,0.80)
C_{23}	M	M	P	M	E	(0.30,0.55,0.75)

C_{31}	M	M	S	M	E	(0.40,0.65,0.85)
C_{32}	M	P	S	P	M	(0.20,0.45,0.70)
C_{33}	E	M	U	S	M	(0.35,0.55,0.75)
C_{34}	M	U	P	M	P	(0.10,0.30,0.55)
C_{35}	U	M	M	M	P	(0.15,0.35,0.60)
C_{41}	U	M	U	S	P	(0.15,0.30,0.55)
C_{42}	M	M	M	S	P	(0.25,0.50,0.75)
C_{43}	M	M	M	S	S	(0.35,0.60,0.85)
C_{44}	M	S	M	U	S	(0.30,0.50,0.75)
C_{51}	S	S	E	M	S	(0.50,0.75,0.95)
C_{52}	U	E	E	M	S	(0.45,0.65,0.80)
C_{53}	S	E	M	U	U	(0.30,0.45,0.65)
C_{54}	U	U	M	M	U	(0.10,0.20,0.45)

Table 4.9: Priority weights (crisp representation) against individual 2nd level indices

C_{ij}	Priority weight (crisp representation)
C_{11}	0.83
C_{12}	0.63
C_{13}	0.67
C_{14}	0.67
C_{21}	0.83
C_{22}	0.75
C_{23}	0.71

C_{31}	0.66
C_{32}	0.66
C_{33}	0.75
C_{34}	0.66
C_{35}	0.75
C_{41}	0.49
C_{42}	0.49
C_{43}	0.52
C_{44}	0.47
C_{51}	0.50
C_{52}	0.62
C_{53}	0.66
C_{54}	0.79

Table 4.10: Priority weight (crisp representation) against individual 1st level indices

C_i	Priority weight (crisp representation)
C_1	0.56
C_2	0.48
C_3	0.65
C_4	0.59
C_5	0.54

Table 4.11: Appropriateness rating (crisp representation) against individual 2nd level indices for alternative suppliers as **A_1**, **A_2** and **A_3**

C_{ij}	Computed rating (crisp representation)		
	A_1	A_2	A_3
C_{11}	0.71	0.76	0.76
C_{12}	0.36	0.50	0.46
C_{13}	0.50	0.59	0.41
C_{14}	0.59	0.67	0.76
C_{21}	0.50	0.59	0.59
C_{22}	0.59	0.93	0.67
C_{23}	0.50	0.67	0.54
C_{31}	0.41	0.50	0.64
C_{32}	0.50	0.41	0.45
C_{33}	0.41	0.59	0.55
C_{34}	0.31	0.36	0.31
C_{35}	0.36	0.45	0.36
C_{41}	0.36	0.19	0.33
C_{42}	0.45	0.36	0.50
C_{43}	0.50	0.55	0.60
C_{44}	0.41	0.38	0.51
C_{51}	0.54	0.55	0.74
C_{52}	0.45	0.64	0.64
C_{53}	0.50	0.41	0.46
C_{54}	0.11	0.33	0.24

Table 4.12: Appropriateness rating (crisp representation) against individual 1st level indices for alternative suppliers as **A_1**, **A_2** and **A_3**

C_i	Computed rating (crisp representation)		
	A_1	A_2	A_3
C_1	1.55	1.80	1.72
C_2	1.22	1.67	1.38
C_3	1.40	1.63	1.62
C_4	0.84	0.73	0.95
C_5	0.96	1.20	1.26

Table 4.13: Computed normalized decision-making matrix

C_i	Normalized decision-making matrix (normalized rating)		
	A_1	A_2	A_3
C_1	0.86	1.00	0.95
C_2	0.73	1.00	0.83
C_3	0.86	1.00	0.99
C_4	0.89	0.77	1.00
C_5	0.76	0.96	1.00

Table 4.14: The weighted normalized decision-making matrix

C_i	Weighted normalized rating		
	A_1	A_2	A_3
C_1	0.48	0.55	0.53
C_2	0.35	0.48	0.39
C_3	0.55	0.65	0.64
C_4	0.53	0.46	0.59
C_5	0.42	0.52	0.55

Table 4.15: Evaluation of ranking score and corresponding ranking order of candidate alternatives as $\mathbf{A_1}$, $\mathbf{A_2}$ and $\mathbf{A_3}$

A_i (Alternatives)	Final evaluation score (M)	Ranking order
A_1	2.33	3
A_2	2.65	2
A_3	2.71	1

Table 4.16: Computed fuzzy multi-criteria group decision making (FMCGDM) matrix

A_i (Alternative)	Computed fuzzy rating of individual 1st level indices				
	C_1	C_2	C_3	C_4	C_5
A_1	(0.20,0.57,1.22)	(0.23,0.53,1.08)	(0.12,0.39,1.03)	(0.10,0.43,1.43)	(0.11,0.36,1.03)
A_2	(0.29,0.66,1.24)	(0.35,0.76,1.31)	(0.18,0.46,1.06)	(0.09,0.35,1.25)	(0.18,0.46,1.13)
A_3	(0.25,0.63,1.28)	(0.26,0.62,1.18)	(0.15,0.46,1.14)	(0.12,0.48,1.57)	(0.17,0.48,1.22)

Table 4.17: Weighted normalized decision matrix and fuzzy positive and negative ideal solutions

A_i (Alternative)	C_1	C_2	C_3	C_4	C_5
A_1	(0.06,0.24,0.70)	(0.05,0.18,0.58)	(0.06,0.24,0.61)	(0.03,0.16,0.69)	(0.03,0.16,0.61)
A_2	(0.09,0.28,0.72)	(0.08,0.26,0.70)	(0.08,0.28,0.63)	(0.03,0.13,0.60)	(0.05,0.21,0.66)
A_3	(0.07,0.27,0.74)	(0.06,0.21,0.63)	(0.07,0.28,0.68)	(0.03,0.18,0.76)	(0.05,0.21,0.72)
$(Fuzzy\ positive\ ideal\ solution)\ A^+$	(0.09,0.28,0.74)	(0.08,0.26,0.70)	(0.08,0.28,0.68)	(0.03,0.18,0.76)	(0.05,0.21,0.72)
$(Fuzzy\ negative\ ideal\ solution)\ A^-$	(0.06,0.24,0.70)	(0.05,0.18,0.58)	(0.06,0.24,0.61)	(0.03,0.13,0.60)	(0.03,0.16,0.61)

Table 4.18: Distance (separation measures) d_i^+ as well as d_i^- and closeness coefficient CC_i of alternatives **A_1**, **A_2** and **A_3**

A_i (Alternative)	d_i^+	d_i^-	CC_i	*Ranking order*
A_1	0.285	0.055	0.16	3
A_2	0.169	0.192	0.53	2
A_3	0.072	0.277	0.79	1

Table 4.19: Difference between two MCDM approaches adapted in this paper: FMLMCDM and Fuzzy-TOPSIS

Sl. No.	FMLMCDM	Fuzzy-TOPSIS
1	Works on multi-level multi-criteria model. Each main criterion is divided into sub-criteria; each sub-criterion is divided into sub-sub-criteria and so on.	Explores a set of criterions at single level.
2	Can consider both subjective as well as objective data.	Proposed approach can consider only subjective (fuzzy) data.
3	Fuzzy appropriateness rating as well as fuzzy priority weight needs to be defuzzified first. Then by layer-wise (higher level to lower level of the criteria hierarchy), a unique supplier selection score is computed.	Based on 'Fuzzy Weighted Average' rule appropriateness ratings as well as priority weights of sub-criteria (at higher level) are utilized to compute appropriateness rating of a criterion (at higher/preceding level).
3	The unique supplier selection score is used to rank the alternative suppliers.	It computes an ideal solution and anti-ideal solution set. Then separation distances of each alternative with respect to ideal and anti-ideal solution are computed. Finally, a closeness coefficient is computed to rank the alternative suppliers.
4	Fuzzy operational rules are not utilized here. Because, initially all fuzzy data are converted into representative crisp values (defuzzified values). At every stage exploration of defuzzified values may increase chance of error.	Fuzzy operational rules are utilized here. Defuzzification of a fuzzy number is not required at all.

CHAPTER 5

PERFORMANCE EVALUATION OF FLEXIBLE SUPPLY CHAIN

5.1 Coverage

Supply chain flexibility is considered as a major determinant of competitiveness in the global business market today. Flexibility is the ability to adapt, in a reversible manner, to an existing situation, as opposed to evolution, which is irreversible. Companies must realize the real competition is not firm-to-firm, but supply chain-to-supply chain. Flexibility is the organization's ability to satisfy an increasing variety of customer expectations without excessive cost, time, organizational disruptions, or performance losses. Effective control of supply chain flexibility can improve overall organizational performance. However, the literature addressing different aspects of assessment as well as appraisement of supply chain flexibility remains limited. In order to fill existing research gap, present study thus builds a group decision-making structural hierarchy model towards assessment as well as benchmarking of flexibility extent in supply chain management. This study presents a framework for evaluating supply chain flexibility through comprehensive analysis of past literature and identifies five elements (assessment indices) for characterizing supply chain flexibility viz. supply network flexibility, operations systems flexibility, logistics process flexibility, information system flexibility, and organizational design flexibility. The subjectivity of the flexibility indices have been tackled through exploration of the concept of fuzzy set theory; thus, enabling decision-making which involves linguistic expert judgment. The proposed framework may help management practitioners to appraise existing (flexibility level) performance extent of the supply chain in which a company operates, as well as to compare flexibility performance of different enterprises running under similar supply chain architecture. The research has further been extended to identify ill-performing areas (in view of flexibility) of the entire organizational supply chain network.

5.2 Supply Chain Flexibility Dimensions

In the present work, SCF has been assessed in terms of five important evaluation indices (metrics or dimensions) (Source: Shian-Jong, 2011) (Table 5.1): Supply network flexibility, Operations systems flexibility, Logistics processes flexibility, Information systems flexibility, and Organizational design flexibility. Each flexibility dimension has been characterized by its efficiency, responsiveness, versatility as well as robustness.

5.2.1 Supply Network Flexibility

Supply flexibility is referred to the ability to reconfigure the supply chain, altering the supply of product in line with customer demand. The flexibility of supply includes flexibility in establishing the relationships with partners. Companies may choose to solicit short-term bids, enter into long-term contracts and strategic supplier relationships, form joint ventures, form consortiums, create problem-solving councils or vertically integrate.

Interdependencies among supply chains imply conditions that are very different from what traditional conceptions of a supply chain suggest (Dubois et al., 2004). To effectively evaluate all of the network alternatives, firms must consider millions of possible combinations far too complex for a simple spreadsheet. In order to consider the 'what-if' alternatives of a network, firms need to invoke network optimization and simulation tools used in conjunction with transportation modeling or inventory optimization to create the optimal scenarios [Source: www.scdigest.com].

5.2.2 Operations Systems Flexibility

Operations system flexibility (both manufacturing and service) refers to the ability to configure assets and operations to react to emerging customer trends (product changes, volume, mix) at each node of the supply chain. Operation flexibility focuses on intra-organization abilities of the strategic business unit within an organization, including the flexibility of manufacture and resources usage. Manufacturing flexibility represents organizational abilities to produce a variety of products by the use of advanced technology and automatic capability, concretely consisting of product flexibility and technology flexibility. Resource flexibility refers to the ability to dynamically reallocate units of resource in response to shifting bottlenecks, concretely consisting of labor flexibility, financial flexibility and machine flexibility. It is a comprehensive consideration to use three different aspects to measure resource flexibility (Li and Qi, 2008).

5.2.3 Logistics Processes Flexibility

Logistics flexibility is the ability to cost effectively receive and deliver product as sources of supply and customers change (customer location changes, globalization, postponement). It is the ability of the firm to effectively and rapidly respond to customer requirements for delivery, support and service (Perry 1991; Davis 1993; Day 1994; Bowersox and Closs 1996; Zhang et al. 2002; Zhang et al. 2005). Therefore, logistics flexibility takes care of a fluent material flow through manufacturing and a rapid delivery to the customers. Logistics flexibility has four components: physical supply flexibility and purchasing flexibility, (which are the competences), and physical distribution flexibility and demand management flexibility, (which are the customer facing capabilities). Physical supply flexibility is the ability of the firm to rapidly and exactly provide a variety of inbound and transportation of materials and supplies, warehousing and inventory for production (Langley and Holcomb 1992; Day 1994; Bowersox and Closs 1996; Narasimhan and Carter 1998; Zhang et al. 2002; Zhang et al. 2005). The definition of purchasing flexibility is the ability of a firm to rapidly and effectively make agreements to buy a variety of materials and supplies (Narasimhan and Carter 1998; Porter 1998; Van Hoek 2001; Zhang et al. 2002; Zhang et al. 2005). The range of these flexibilities could be established by the number of inbound transportation modes and the variety of materials supplied, packed and purchased. Mobility is measured by the development of time and efficiency of the different transportation modes and packages and the difference in time and/or the costs to fulfill the requested variety of materials. Uniformity is assessed by the quality and reliability of the different incoming goods and the quality of the purchasing process and the materials purchased. The competences physical supply and purchasing flexibility has an impact on the customer indirectly by the quality, speed and cost of the materials that are purchased and the effectively and efficiently way the materials are supplied (Zhang et al. 2002; Zhang et al. 2005).

5.2.4 Information Systems Flexibility

Information systems flexibility is the ability to align information system architectures and systems with the changing information needs of the organization as it responds to changing customer demand. Information systems flexibility focuses on the ability to synchronize information systems with supply chain partners, share information across internal business processes and pass information along the chain. Effective information communicating mechanism can improve transparency, avoid lost sales, speed up payment cycles, create trust, avoid over-production and reduce inventories (Stevenson and Spring, 2007). The information systems and technologies must be reconfiguration, reusability and ease of extendibility, which allow organizations to be more effectively coordinated at the network-level. There are three items that affect information sharing degree. They include: information transmission speed, information transmission quality and information sharing depth.

5.2.5 Organizational Design Flexibility

Organizational flexibility is the ability to align labor force skills to the needs of the supply chain to meet customer service/demand requirements. The ability of an organization to move employees to other duties or responsibilities within the company, functional flexibility reflects an organization's ability to adapt to changing conditions and requirements, and is affected by issues such as training, management, and outsourcing. Workplace management and organization technique that optimizes human resources through flexibility based on segmenting the employees into peripheral and core groups. The core groups of employees are difficult to replace because they have a specific skill set or experience, while the peripheral group consists of employees who could easily be replaced or are only needed in the organization for either peak periods or on specific tasks. Work practice (explained by the employer in employment policies and contracts) that allows the employees a certain degree of freedom in deciding how the work will be done and how they will coordinate their schedules with those of other employees. The employer sets certain limits such as minimum and maximum number of hours of work every day, and the core time during which all employees must be present then a group of employees that understand how to perform a variety of different jobs and functions within a company. Many companies desire a more flexible workforce to avoid having the loss of any particular staff member damage its prospects for success, and so they might implement an extensive cross training program for employee.

5.3 Problem Definition

Supply chain flexibility has become such a popular avenue in modern business management today. It brings the revolutionary philosophy and approach to manage the business with sustained competitiveness. However, the existing performance measurement theory fails to provide its necessary support in strategy development, decision making and performance improvement. To this end, present work attempts to introduce a different performance appraisement forum in order to evaluate existing performance on organizational supply chain flexibility. The proposed appraisement modules may help the industries for continuous monitoring of supply chain flexibility performance; it can identify week performing areas which need future improvement. Most of the performance metrics being subjective in nature, a decision-making group has been recommended to collect subjective evaluation information using linguistic scale. Linguistic information has been correlated with fuzzy logic to provide a strong mathematic base to support the aforesaid evaluation and related decision-modeling.

5.4 Fuzzy Approach

Fuzzy set theory has been studied extensively over the past 30 years. Most of the early interest in fuzzy set theory pertained to representing uncertainty in human cognitive processes. Fuzzy set theory is now applied to problems in engineering, business, medical and related health sciences, and the natural sciences. Fuzzy set theory is being recognized as an important problem modeling and solution technique.

In real life, the modeling of many situations may not be sufficient or exact, as the available data are inexact, vague, imprecise and uncertain by nature (Sarami et al., 2009). Moreover, the decision making processes that take place in such situations are also based on uncertain and ill-defined information. In the real world decision-making situation, decision-makers usually confront with a high degree of uncertainties and fuzziness. Fuzzy set theory is considered the most effective methods in managing vagueness and uncertainty problems. The concept of fuzzy sets was introduced by (Zadeh, 1965) to mathematically represent data and information possessing non-statistical uncertainties and to provide formalized tools for dealing with imprecision intrinsic to many problems (Kahraman et al., 2007). In order to model such situations, fuzzy set theory was introduced to express the linguistic terms of decision marking processes (Liao and Kao, 2011).

Fuzzy sets and fuzzy logic are powerful mathematical tools employed for modeling uncertain systems. A fuzzy set is an extension of a crisp set. A crisp set only allows full membership or non-membership, while fuzzy sets allow partial membership. The theoretical fundaments of fuzzy set theory were overviewed by (Chen, 2000). This section presents the concepts and properties of the generalized trapezoidal fuzzy numbers as well as the generalized interval-valued trapezoidal fuzzy numbers. In addition, the arithmetic operations and aggregation of the generalized interval-valued trapezoidal fuzzy numbers are discussed.

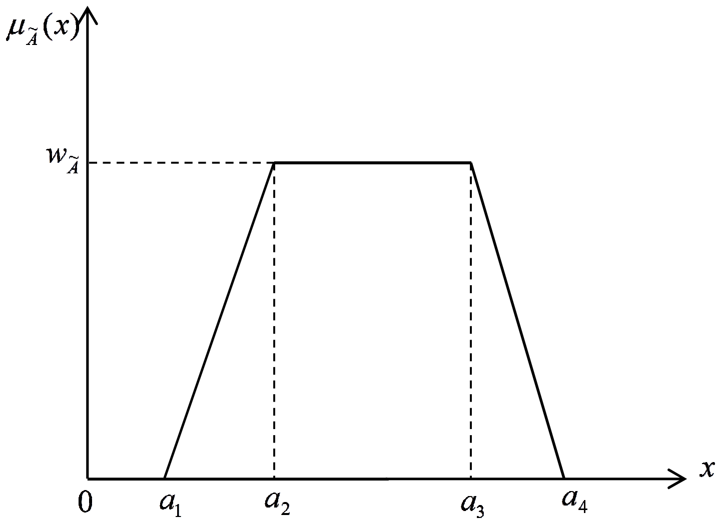

Fig. 5.1: Trapezoidal fuzzy number $\tilde{A}$

5.4.1 The Theory of Generalized Trapezoidal Fuzzy Numbers

A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$. A trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$ as shown in Fig. 5.1 and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x-a_4}{a_3-a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty,\ a_1) \cup (a_4,\ \infty) \end{cases} \tag{5.1}$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in (0,1)$

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{B}})$ are two trapezoidal fuzzy numbers, then the operational rules of the trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows:

Addition Operation:

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{A}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{B}}) =$$

$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{A}}, w_{\tilde{B}})) \quad (5.2)$$

Substation Operation:

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{A}}) - (b_1, b_2, b_3, b_4; w_{\tilde{B}}) =$$

$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{A}}, w_{\tilde{B}})) \quad (5.3)$$

Multiplication Operation:

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{A}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{B}}) =$$
$$\tilde{a} \otimes \tilde{b} = (a_1 \times b_1,\ a_2 \times b_2,\ a_3 \times b_3,\ a_4 \times b_4; \min(w_{\tilde{A}}, w_{\tilde{B}})) \quad (5.4)$$

Division Operation:

$$\tilde{a} / \tilde{b} = {(a_1, a_2, a_3, a_4; w_{\tilde{A}})} \Big/ {(b_1, b_2, b_3, b_4; w_{\tilde{B}})}$$

$$= (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min(w_{\tilde{A}}, w_{\tilde{B}})) \quad (5.5)$$

5.4.2 Ranking of Fuzzy Numbers: ‘Incentre of Centroid’ Method

Ranking of fuzzy numbers plays an important role in approximate reasoning, optimization, forecasting, decision making, scheduling and risk based analysis practices. The ranking method for fuzzy numbers was first proposed by Jain (1976) for decision making in fuzzy environment by representing the ill-defined quantities as a fuzzy sets. Wang and Kerre (2001) classified all the ranking methods into three categories and proposed seven reasonable properties to evaluate the ranking method. Then, ranking of fuzzy numbers by preference ratio (Modarres and Nezhad, 2001), left and right dominance (Chen and Lu, 2001), area between the centroid point and original point (Chu and Tsao, 2002), sign distance (Abbasbandy and Asady, 2006) and distance minimization (Asady and Zendehnam, 2007) have been proposed. Thorani et al. (2012a) have illustrated a ranking method for ordering fuzzy numbers using orthocentre of centroid method. Thorani et al. (2012b) provided a formulation towards computing equivalent crisp score against a particular fuzzy number. This concept is utilized to rank a set of fuzzy numbers with the help of computed crisp score. This concept of crisp evaluation has been explored in this research towards development of an efficient risk assessment module. The mathematical basis of this concept has been reproduced in later part of this section.

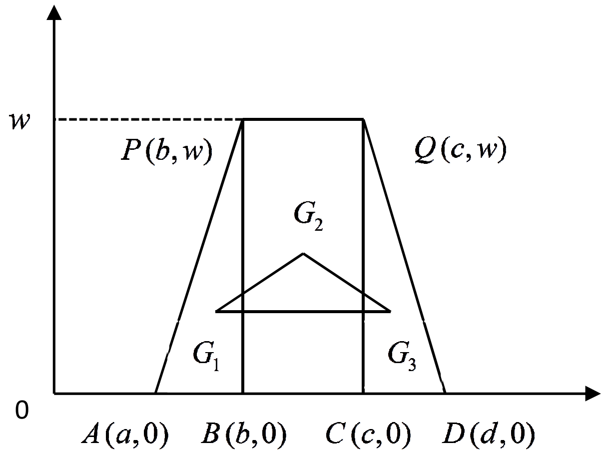

Fig. 5.2: Trapezoidal Fuzzy Number [Thorani et al., 2012c]

This ranking method proposed by (Thorani et al., 2012c) has been adapted in the present research. The Centroid of a trapezoid is considered as the balancing point of the trapezoid (Fig. 5.2). Divide the trapezoid into three plane figures. These three plane figures are a triangle (APB), a rectangle (BPQC), and a triangle (CQD), respectively. Let the Centroid of the three plane figures be G_1, G_2 and G_3 respectively. The in center of these Centroid G_1, G_2 and G_3 is taken as the point of reference to define the ranking of generalized trapezoidal fuzzy numbers. The reason for selecting this point as a point of reference is that each Centroid point are balancing points of each individual plane figure, and the in centre of these Centroid points is a much more balancing point for a generalized trapezoidal fuzzy number . Therefore, this point would be a better reference point than the Centroid point of the trapezoid.

Consider a generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ (Fig. 5.1). The Centroid of the three plane figures are respectively.

$$G_1 = \left(\frac{a+2b}{3}, \frac{w}{3} \right) \tag{5.6}$$

$$G_2 = \left(\frac{b+c}{3}, \frac{w}{3} \right) \tag{5.7}$$

$$G_3 = \left(\frac{2c+d}{3}, \frac{w}{3} \right) \tag{5.8}$$

Equation of the line $\overleftrightarrow{G_1G_3}$ is $y = \frac{w}{3}$ and G_2 does not lie on the line $\overleftrightarrow{G_1G_3}$. Therefore G_1, G_2 and G_3 are non-collinear and they form a triangle. We define the In centre $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ of the triangle with vertices G_1, G_2 and G_3 of the generalized trapezoidal fuzzy number as $\tilde{A} = (a,b,c,d;w)$ as

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma}, \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma} \right) \tag{5.9}$$

where

$$\alpha = \frac{\sqrt{(c-3b+2d)^2 + w^2}}{6}, \beta = \frac{\sqrt{(2c+d-a-2b)^2 + w^2}}{3}, \gamma = \frac{\sqrt{(3c-2a-b)^2 + w^2}}{6}$$

As a special case, for triangular fuzzy number $\tilde{A} = (a,b,c,d;w)$ i.e. c = b the in centre of centroid is given by

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \tag{5.10}$$

where

$$x = \frac{\sqrt{(2d-2b)^2 + w^2}}{6}, y = \frac{\sqrt{(d-a)^2 + w^2}}{3}, z = \frac{\sqrt{(2b-2a)^2 + w^2}}{6}$$

The ranking function of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ which maps the set of all fuzzy numbers to a set of real numbers

$$R(\tilde{A}) = (\bar{x}_0 \times \bar{y}_0) = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \qquad (5.11)$$

This is the area between the in center of the centroids $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ as denied in Eq. 5.10, and the original point.

5.5 Procedural Hierarchy: Case Application

Procedural steps of supply chain flexibility performance appraisement module have been highlighted below.

Step 1: Formation of a group of experts (Decision-Makers DMs) for evaluating and appraising of supply chain flexibility performance.

Step 2: Selection of appropriate linguistic scale to represent DMs' subjective judgment in relation importance grade against evaluation indices and at the same time to rate the performance extent of individual performance indices.

Step 3: Assignment of performance ratings as well as importance grade of indices using linguistic terms.

Step 4: Approximation of DMs' subjective judgment (in linguistic terms) by Generalized Trapezoidal Fuzzy Numbers (GTFNs).

Step 5: Estimation of overall flexibility appraisement index.

Step 6: Identification of ill-performing areas which need future improvement.

Aforesaid appraisement module has been adopted as case application in an Indian famous automobile part manufacturing industry in Eastern part of India. A two-level evaluation index system has been adapted from the reporting of (Shian-Jong, 2011) as shown in Table 5.1. A suitable linguistic scale has been chosen (Table 5.2) following which experts could express their subjective judgment in relation to priority importance as well as performance extent (appropriateness rating) of individual evaluation indices.

For evaluating importance grade (priority extent) of individual evaluation indices at different levels, a committee of three decision-makers (DMs), DM_1, DM_2, DM_3 has been formed to express their subjective preferences (priority importance) in linguistic terms (Tables 5.3-5.4). Similarly, the decision-making group has also been instructed to use the linguistic scale (as shown in Table 5.2) to express their subjective judgment against performance rating of each 2nd level evaluation indices (Table 5.5).

Using the concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs) in fuzzy set theory, the linguistic variables have been approximated by appropriate Generalized Trapezoidal Fuzzy Numbers as per Table 5.2. The aggregated fuzzy appropriateness rating against individual 2nd level indices along with corresponding aggregated fuzzy importance weight has been computed (as shown in Table 5.6). Fuzzy average rule has been adapted here towards computing aggregated fuzzy weight as well as aggregated fuzzy rating against individual 2nd level indices.

Considering a 2-level evaluation index system hierarchy for SCF performance appraisal; the following notations to be used for computational purpose.

C_i = i^{th} 1st level evaluation index; $i = 1,2,...,m.$

C_{ij} = j^{th} 2nd level evaluation index which is under i^{th} 1st level evaluation index C_i; $j = 1,2,...,n.$

The computed fuzzy performance rating of individual 1st level evaluation indices can be calculated as (Eq. 5.12) and shown in Table 5.7.

$$U_i = \frac{\sum_{j=1}^{n}\left(w_{ij} \otimes U_{ij}\right)}{\sum_{j=1}^{n} w_{ij}} \tag{5.12}$$

Here U_{ij} represents aggregated fuzzy performance measure (rating) and w_{ij} represent aggregated fuzzy importance grade corresponding to attributes C_{ij} at 2nd level. Also, U_i represents the computed fuzzy performance measure (rating) corresponding to the index C_i at 1st level.

Thus, overall fuzzy performance index $U(FPI)$ can be obtained as follows.

$$U(FPI) = \frac{\sum_{i=1}^{m}\left(w_i \otimes U_i\right)}{\sum_{i=1}^{m} w_i} \tag{5.13}$$

Here U_i = rating of i^{th} 1st level evaluation index C_i; w_i = Importance grade of i^{th} 1st level evaluation index C_i.

The FPI thus becomes **[(0.230, 0.446, 1.590, 3.045; 1)]** for the said candidate company under consideration. This reflects the overall supply chain flexibility index in terms of fuzzy value.

After evaluating FPI, simultaneously it is felt indeed necessary to identify and analyze weak (ill-performing) areas in which organizational SC may require future improvement to enhance its overall flexibility degree. *Fuzzy Performance Importance Index (FPII)* may be used to identify these ill-performing areas. FPII combines the performance rating and importance grade of various 2nd level indices. The higher the FPII of a factor, the higher is the contribution. The concept of FPII was introduced by (Lin et al., 2006) for agility extent measurement in supply chain Flexibility.

$$FPII_{ij} = w_{ij}^{'} \otimes U_{ij} \tag{5.14}$$

Here, $w_{ij}^{'} = [[(1,1,1,1;1)] - w_{il}]$

U_{ij} is the rating and w_{ij} is the importance weight of j_{th} index (at 2nd level).

Fuzzy Performance Importance Index (FPII) has been computed against each of the 2nd level evaluation indices and FPII values are shown in Table 5.8.

After evaluation the FPII values, the crisps scores corresponding to FPII of individual 1st level indices have been computed by exploring the concept of 'incentre of centroids' method (Eq. 5.11); according to that particular representative crisp score which corresponds to higher value is assumed to have high contribution; it indicates high performance and high ranking order. According to the descending order of the crisp score (ranking function value) of individual 1st level performance indices or crisps value; the ranking order of various performance indices has been determined and it shown in Table 5.8. By this way weak (ill-performing) areas of supply chain flexibility network can be identified which require future attention for subsequent improvement in order to boost up overall SC flexibility.

5.6 Managerial Implications

The work demonstrates a fuzzy embedded feasible appraisement platform for analyzing existing SCF performance; this will create an opportunity to use across a variety of SCF situations and thus generate a systematic and logical evaluation forum for comparison and benchmarking of different supply chain flexibility scenarios across different industries. Based on the analyzed results, the managers can find out the problems (ill-performing areas) and improve organizational SCF performance. Proposed fuzzy based flexibility assessment approach is seemed innovative and creates a new way for other disciplines of decision sciences. In the same way, managers need to understand that depending on their situation and their own organization's relationship with the entire SCF, they must strive for the right selection of flexibility dimensions, to make a good choice to reach their predetermined goal. This is important because every flexibility dimension is not equally related to a specific firm performance measure and it is meaningless to develop a flexibility strategy which increases flexibility but not reaches the goal (De Treville and Vanderhaeghe 2003; Sánchez and Pérez Pérez, 2005); or like (Golden and Powell, 2000) described it interpreting: "an organization can be flexible in some way and less flexible in others".

To obtain flexibility it is not sufficient to buy flexibility, it must be planned and managed according to the changing circumstances to gain its benefits (Oke 2003; Boyle 2006). This is only possible from a broad perspective on flexibility and when taking all important flexibility dimensions for that particular situation together into consideration and not one at the time.

Aforesaid study thus builds a group decision-making procedural hierarchy of flexibility in SCM development. This study presents a framework for evaluating supply chain flexibility followed by an evaluation hierarchy with flexibility dimensions and related metrics, and an evaluation scheme that uses a fuzzy logic base to evaluate supply chain flexibility.

The proposed fuzzy based flexibility appraisement framework can assist managers in properly diagnosing and deploying supply chain flexibility strategies. The ill-performing areas thus identified should be improved in future for promoting overall supply chain flexibility. The proposed framework can also be used to assess the various options for exploiting or acquiring flexibility strategies.

5.7 Concluding Remarks

Organization are dealing with complex, continuous changing and uncertain environments due trends in the area of globalization, technical changes and innovations and changes in the customers' needs and expectations. To cope with the increasingly uncertain and quickly changing environment firms strive for flexibility.

In this context, an efficient fuzzy method based on the Generalized Trapezoidal Fuzzy Numbers (GTFN) set theory and the concept of 'Incentre of Centroid' method (used for evaluating representative crisp score against a fuzzy number) has been proposed for assessment of SCF and related decision making.

This approach is seemed appropriate for situations where assessment information may be qualitative, or precise quantitative information is either unavailable or too costly to compute. However, the specialty of this methodology is that it uses approximate reasoning, and experts must perfectly distinguish the set of terms under a similar conception, and must use linguistic terms to express their opinions. The above method with the group decision making structure in the presence of multiple dimensions and related multiple metrics, used to evaluate the performance of SCF, is very useful in supply chain development. The model described in this study to evaluate the performance of SCF involves a group of experts and interactive consensus analysis. Therefore, the evaluation results are more objective and unbiased than those individually assessed.

Table 5.1: The evaluation hierarchy of supply chain flexibility

Goal	1st level indices	2nd level indices
Supply Chain Flexibility, C	Supply network flexibility,C_1	Efficiency,C_{11}
		Responsiveness,C_{12}
		Versatility,C_{13}
		Robustness,C_{14}
	Operations systems flexibility,C_2	Efficiency,C_{21}
		Responsiveness,C_{22}
		Versatility,C_{23}
		Robustness,C_{24}
	Logistics processes flexibility,C_3	Efficiency,C_{31}
		Responsiveness,C_{32}
		Versatility,C_{33}
		Robustness,C_{34}
	Information systems flexibility,C_4	Efficiency,C_{41}
		Responsiveness,C_{42}
		Versatility,C_{43}
		Robustness,C_{44}
	Organizational design flexibility,C_5	Efficiency,C_{51}
		Responsiveness,C_{52}
		Versatility,C_{53}
		Robustness,C_{54}
[Source: Chuu, 2011]		

Supply chain flexibility: taxonomic definitions

Performance indicator	Explanation
Supply network flexibility	The ability to reconfigure the supply chain, altering the supply of product in line with customer demand at each participating company of the supply chain.
Operations systems flexibility	The ability of operation, including the capabilities to change products, equipment, people and processes within the operations function.
Logistics processes flexibility	The ability of the integrated logistic system to distribute and deliver the product economically.
Information systems flexibility	The ability to align information system architectures and systems with the changing information needs of the organization as it responds to changing customer demand.
Organizational design flexibility	The ability to align labor force skill to the needs of the supply chain to meet customer service/demand requirements at each participating company of the supply chain.
Efficiency	The comparison of what is actually produced or performed with what can be achieved with the same consumption of resources (money, time, labor, etc.). It is an important factor in determination of productivity as well as effectiveness.
Responsiveness	The rating at which a system reacts to new circumstances, and can be assessed by the suitability rating with a speedy response.
Versatility	The rating of a system to accommodate foreseen environmental uncertainties effectively, and can be assessed for its suitability rating with a range of planned options.
Robustness	The rating of a system to cope with unforeseen environmental uncertainties effectively, and can be assessed by the suitability rating with a range of unplanned options.

[Source: Shian-Jong, 2011]

Table 5.2: Nine-member linguistic terms and their corresponding fuzzy representations

Linguistic terms for importance grade	Linguistic terms for performance rating	Fuzzy representation
DL: Definitely low	DL: Definitely low	(0.0, 0.0, 0.0, 0.0; 1.0)
VL: Very low	VL: Very low	(0.0, 0.0, 0.02, 0.07; 1.0)
L: Low	L: Low	(0.04, 0.10, 0.18, 0.23; 1.0)
ML: More or less low	ML: More or less low	(0.17, 0.22, 0.36, 0.42; 1.0)
M: Middle	M: Middle	(0.32, 0.41, 0.58, 0.65; 1.0)
MH: More or less high	MH: More or less high	(0.58, 0.63, 0.80, 0.86; 1.0)
H: High	H: High	(0.72, 0.78, 0.92, 0.97; 1.0)
VH: Very high	VH: Very high	(0.93, 0.98, 1.0, 1.0; 1.0)
DH: Definitely high	DH: Definitely high	(1.0, 1.0, 1.0, 1.0; 1.0)

Table 5.3: Importance grade (in linguistic term) of 2nd level indices assigned by DMs

2nd level indices	Importance grade (in linguistic scale) of 2nd level indices assigned by DMs		
	DM1	DM2	DM3
C_{11}	H	H	VH
C_{12}	MH	H	H
C_{13}	H	MH	MH
C_{14}	MH	MH	MH
C_{21}	VH	VH	DH
C_{22}	H	VH	DH
C_{23}	VH	H	VH
C_{24}	DH	H	H
C_{31}	MH	H	MH
C_{32}	H	MH	H
C_{33}	MH	M	MH
C_{34}	MH	M	H
C_{41}	H	MH	ML
C_{42}	MH	M	M
C_{43}	M	MH	ML
C_{44}	MH	MH	L
C_{51}	L	ML	L
C_{52}	VL	ML	ML
C_{53}	ML	L	ML
C_{54}	DL	L	L

Table 5.4: Importance grade (in linguistic term) of 1st level indices assigned by DMs

1st level indices	Importance grade (in linguistic scale) of 1st level indices assigned by DMs		
	DM1	DM2	DM3
C_1	VH	DH	H
C_2	H	H	H
C_3	DH	VH	DH
C_4	MH	H	MH
C_5	MH	M	MH

Table 5.5: Appropriateness rating (in linguistic term) of 2nd level indices assigned by DMs

2nd level indices	Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs		
	DM1	DM2	DM3
C_{11}	VH	H	MH
C_{12}	H	M	MH
C_{13}	M	H	VH
C_{14}	VH	VH	VH
C_{21}	H	VH	VH
C_{22}	VH	VH	H
C_{23}	H	M	NH
C_{24}	H	M	MH
C_{31}	VH	H	DH
C_{32}	VH	H	DH
C_{33}	H	VH	VH
C_{34}	DH	VH	VH
C_{41}	VH	VH	H
C_{42}	H	H	DH
C_{43}	VH	M	H
C_{44}	DH	M	VH
C_{51}	H	MH	H
C_{52}	VH	MH	H
C_{53}	MH	H	VH
C_{54}	MH	H	DH

Table 5.6: Aggregated fuzzy importance grade and aggregated fuzzy rating of 2nd level indices

2nd level indices	Aggregated Fuzzy importance grade, w_{ij}	Aggregated Fuzzy Rating, U_{ij}
C_{11}	[0.790, 0.846, 0.946, 0.980;1]	[0.743, 0.796, 0.906, 0.943;1]
C_{12}	[0.673, 0.730, 0.808, 0.933;1]	[0.540, 0.606, 0.766, 0.826;1]
C_{13}	[0.626, 0.680, 0.840, 0.896;1]	[0.656, 0.723, 0.833, 0.873;1]
C_{14}	[0.580, 0.630, 0.800, 0.860;1]	[0.930, 0.980, 1.000, 1.000;1]
C_{21}	[0.953, 0.986, 1.000, 1.000;1]	[0.860, 0.913, 0.973, 0.990;1]
C_{22}	[0.883, 0.920, 0.973, 0.990;1]	[0.860, 0.913, 0.973, 0.990;1]
C_{23}	[0.860, 0.913, 0.973, 0.990;1]	[0.540, 0.606, 0.766, 0.826;1]
C_{24}	[0.813, 0.853, 0.946, 0.980;1]	[0.540, 0.606, 0.766, 0.826;1]
C_{31}	[0.626, 0.680, 0.840, 0.896;1]	[0.883, 0.920, 0.973, 0.990;1]
C_{32}	[0.673, 0.730, 0.880, 0.933;1]	[0.883, 0.920, 0.973, 0.990;1]
C_{33}	[0.493, 0.556, 0.726, 0.790;1]	[0.860, 0.913, 0.973, 0.990;1]
C_{34}	[0.540, 0.606, 0.766, 0.826;1]	[0.953, 0.986, 1.000, 1.000;1]
C_{41}	[0.490, 0.543, 0.693, 0.750;1]	[0.860, 0.913, 0.973, 0.990;1]
C_{42}	[0.406, 0.483, 0.653, 0.710;1]	[0.813, 0.853, 0.946, 0.980;1]
C_{43}	[0.356, 0.420, 0.580, 0.643;1]	[0.656, 0.723, 0.833, 0.873;1]
C_{44}	[0.400, 0.453, 0.593, 0.650;1]	[0.750, 0.796, 0.860, 0.873;1]
C_{51}	[0.083, 0.140, 0.240, 0.293;1]	[0.673, 0.730, 0.880, 0.933;1]

C_{52}	[0.113, 0.146, 0.246, 0.303;1]	[0.743, 0.796, 0.906, 0.943;1]
C_{53}	[0.126, 0.180, 0.300, 0.356;1]	[0.743, 0.796, 0.906, 0.943;1]
C_{54}	[0.026, 0.066, 0.120, 0.153;1]	[0.766, 0.803, 0.906, 0.943;1]

Table 5.7: Aggregated fuzzy priority weight and computed fuzzy rating of 1st level indices

1st level indices	Aggregated fuzzy importance grade, w_i	Computed fuzzy rating, U_i
C_1	[0.883, 0.920, 0.973, 0.990;1]	[0.518, 0.642, 1.050, 1.250;1]
C_2	[0.720, 0.780, 0.920, 0.970;1]	[0.627, 0.808, 0.923, 1.025;1]
C_3	[0.976, 0.993, 1.000, 1.000;1]	[0.605, 0.748, 1.223, 1.466;1]
C_4	[0.626, 0.680, 0.840, 0.896;1]	[0.467, 0.624, 1.203, 1.554;1]
C_5	[0.493, 0.556, 0.726, 0.790;1]	[0.229, 0.458, 1.531, 2.986;1]

Table 5.8: Ranking order of 2nd level indices

2nd level indices	FPII	$R(\tilde{A})$ Crisp Value	Ranking Order
C_1	[0.061, 0.051, 0.028, 0.013; 1]	0.013	4
C_2	[0.176, 0.178, 0.074, 0.031; 1]	0.043	3
C_3	[0.015, 0.005, 0.000, 0.000; 1]	0.001	5
C_4	[0.175, 0.200, 0.193, 0.162; 1]	0.063	2
C_5	[0.116, 0.203, 0.420,0. 627; 1]	0.120	1

CHAPTER 6

PERFORMANCE EVALUATION OF RESILIENT SUPPLY CHAIN

6.1 Coverage

In today's dynamic era of global business, resilience strategy is being adapted and embedded along with traditional supply chain (SC) in order to build supply chain potent, sustainable and tolerable to respond effectively to organizations' internal and external unwanted and undesirable vulnerabilities, disturbances/disruptions as well as disasters. The present work aims at developing a multi-level hierarchical framework (evaluation index system) towards evaluating an 'appraisement index' for measuring and monitoring SC resilient performance of the candidate industry. In this study, vagueness, imprecision, as well as inconsistency associated with subjective evaluation information (aligned with ill-defined assessment indices of SC resilience performance), has been tackled by the application of fuzzy theory. Subjective evaluation information (expressed in linguistic terms) acquired from the committee of decision makers (called expert group), against different resilience indices, has been fruitfully explored through the proposed fuzzy based resilience performance appraisement module. Finally, a case study in an Indian automobile company has been conducted from the perspective of checking effectiveness of the proposed methodology for evaluation of a unified appraisement index indicating SC resilience extent.

6.2 Problem Definition

In recent times, resilience has become more and more important as a 'medicine' for the vulnerability of complex global networks in a risky environment. Many interesting papers were citied on assuring an adequate level of logistic systems resilience. However, there is still a lack of a framework type approach that could be the foundation of building an expert system to support the design and evaluation of supply chain and network resilience. Also, supply chain resilience, as a measure of system performance remains quantitatively vague. The multidimensional nature of resilience, coupled with the multiple stakeholders involved in supply chains, makes the quantification of such a construct difficult. Motivated by this, this work aims to present a novel multi-dimensional view on the development of a quantitative metric for supply chain resilience. The study takes into account the multiple elements identified in the literature as key components of resilience, evaluates their relative strength in capturing the supply chain response to disruptions, and maps a methodological pathway towards a multidimensional resilience metric.

The following research gaps have been identified through an in-depth review of past literature.

1. Lack of logical construct consisting of capabilities-attributes as well as criterions (integrated criteria hierarchy) to describe supply chain resilience extent in industrial perspectives (SC).

2. Subjective assessment of resilience performance (in relation to industrial SC) is generally vague in nature.
3. Lack of systematic framework (mathematic base) to quantify overall supply chain resilience extent (quantitative metric).
4. Supply chain resilience appraisement from Decision-Makers (DMs) viewpoint.
5. Identification of barriers towards achieving SC resilience.

The objectives of the present research have been specifically mentioned below.

1. Understanding of risk and resilience in industrial supply chain.
2. Development of an appraisement framework (evaluation index system) towards assessment of supply chain resilience.
3. Quantitative assessment index of supply chain resilience.
4. Development of efficient Decision Support Systems (DSSs) towards estimating supply chain resilience.
5. Identification of ill-performing supply chain entities (resilience barriers) which require subsequent future improvement plan to enhance supply chain resilience extent.

6.3 Justification on Exploration of Fuzzy Set Theory

Subjective appraisement of supply chain resilience is basically vague in nature; quantitative assessment of overall supply chain resilience is indeed a difficult task. However, assessment of degree of resilience seems important to compare performance extent of candidate industries/organizations; to set a desired goal of supply chain resilience that the companies should try to achieve; to identify ill-performing supply chain entities those are responsible for SC resilience to lag behind. A team of decision-makers (DMs) (or experts) may play a significant role in evaluating organizational supply chain resilience.

The present work considers the task of SC resilience appraisement as a Multi-Criteria Decision Making (MCDM) problem which involves active participation of an expert group in providing expert judgments which are truly qualitative (subjective) in nature (means these cannot be expressed by real numbers or crisp scores). In order to take care the subjectivity of the evaluation indices (performance measures and metrics); collection of linguistic evaluation information provided by a multiple source (group of decision-makers) is indeed essential. After collecting expert opinions (survey data), it is evident to explore a logical mathematic base in order to transform linguistic evaluation information into some numeric data (representation).

Unless linguistic data are transformed into a mathematic representation, it is really difficult to evaluate a quantitative evaluation index (here supply chain resilience performance index). In this context utility of exploring fuzzy set theory deserves mention. The use of fuzzy numbers against inconsistent evaluation information is seemed advantageous.

As most resilience measurements are described subjectively by linguistic terms, which are characterized by incompleteness, inconsistency and vagueness. In this context, fuzzy set theory provides a useful tool to deal with problems in which the attributes and phenomena are imprecise and vague (Zadeh, 1965; Buckley, 1985; Negi, 1989; Kaufmann and Gupta, 1991; Klir and Yuan, 1995; Zimmermann, 1991; Moeinzadeh and Hajfathaliha, 2010; Chen, 1985; Chen and Chen, 2003; Chen and Chen, 2009). During resilient performance evaluation, frequently the data cannot be analyzed by standard statistical methods, either because there are numerous missing records, or because the data are in the form of qualitative rather than quantitative measures.

It is therefore, realized that the exploration of fuzzy set as may prove fruitful in developing efficient Decision Support System(s) (DSS) for SC resilience performance appraisement, thus providing a unique resilience evaluation index (quantitative metric) for the particular SC under consideration. The main objective to carry out this research is to establish a fuzzy based multi-level hierarchical appraisement platform towards SC resilient performance appraisement, benchmarking and related decision-making.

The basic concepts of fuzzy set theory, definitions of fuzzy numbers, membership functions, and fuzzy operational rules could be found in (Dubois and Prade, 1983; Dubois and Prade, 1986; Matarazzo and Munda, 2001; Yu et al., 2013). The concept of fuzzy numbers ranking by '*Maximizing Set and Minimizing Set*' could also be found out in (Chou et al., 2011; Sahu et al., 2012).

6.4 Fuzzy Numbers: Operational Rules

There are various ways of defining fuzzy numbers. The concept of fuzzy numbers is defined as follows (Dubois and Prade, 1983; 1986):

Definition 1: A real fuzzy number A is described as any fuzzy subset of the real line R with membership function f_A that can be generally defined as:

(a) f_A is a continuous mapping from R to the closed interval $[0,\varpi]$, $0 \le \varpi \le 1$;

(b) $f_A(x) = 0$, for all $x \in (-\infty, a]$;

(c) f_A is strictly increasing on $[a, b]$;

(d) $f_A(x) = 1$, for all $x \in [b, c]$;

(e) $f_A(x)$ is strictly decreasing on $[c, d]$;

(f) $f_A(x) = 0$, for all $x \in (d, \infty]$.

Here a, b, c and d are real numbers. Unless elsewhere specified, it is assumed that A is convex and bounded $(i.e. -\infty < a, d < \infty)$.

Definition 2: The fuzzy number $A = [a, b, c, d; \varpi]$ is a trapezoidal fuzzy number if its membership function is given by:

$$f_A(x) = \begin{cases} f_A^L(x), & a \le x \le b, \\ \varpi, & b \le x \le c, \\ f_A^R(x), & c \le x \le d, \\ 0, & otherwise. \end{cases} \quad (6.1)$$

Here $f_A^L : [a, b] \to [0, \varpi]$ and $f_A^R : [c, d] \to [0, \varpi]$ are two continuous mappings from the real line R to the closed interval $[0, \varpi]$. From **Definition1**, it is obvious that f_A^L, the left membership function of fuzzy number A, is continuous and strictly increasing on $[a, b]$, and $f_R^L(x)$, the right membership function of the fuzzy number A, is continuous and strictly decreasing on $[c, d]$. If $\varpi = 1$, then A is a normal fuzzy number; otherwise, it is said to be a non-normal fuzzy number. If $b \ne c$, A is referred to as a fuzzy interval (Dubois and Prade, 1983) or a flat fuzzy number (Matarazzo and Munda, 2001). If $f_A^L(x)$ and $f_R^L(x)$ are both linear, then A is referred to as a trapezoidal fuzzy number and is usually denoted by $A = (a, b, c, d; \varpi)$ or simply $A = (a, b, c, d)$ if $\varpi = 1$. Fig. 6.1 is an illustration of the trapezoidal fuzzy number $A = (a, b, c, d; \varpi)$. In particular, when $b = c$, the trapezoidal fuzzy number is reduced to a triangular fuzzy number; and can be denoted by $A = (a, b, d; \varpi)$ or $A = (a, b, d)$ if $\varpi = 1$. So, triangular fuzzy numbers are special cases of trapezoidal fuzzy numbers:

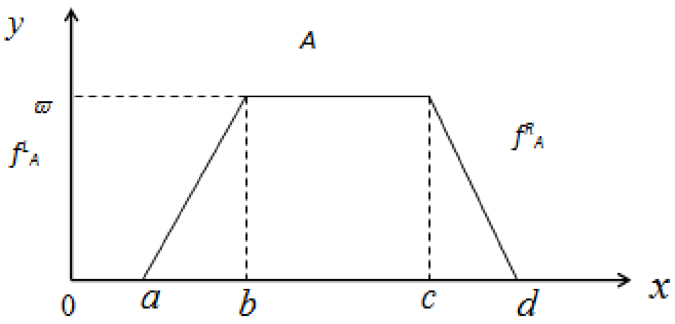

Fig. 6.1: Trapezoidal fuzzy number

Suppose that $A_1 = (a_1, b_1, c_1, d_1; \varpi_1)$ and $A_2 = (a_2, b_2, c_{21}, d_2; \varpi_2)$ are two trapezoidal fuzzy numbers, then the operational rules of the trapezoidal fuzzy numbers $\tilde{a}$ and $\hat{b}$ are shown as follows (Yu et al., 2013):

$$A_1 + A_2 = (a_1, b_1, c_1, d_1; \varpi_1) + (a_2, b_2, c_2, d_2; \varpi_2)$$

$$(a_1 + a_2, b_1 + b_2, c_3 + c_3, d_4 + d_4; \min(\varpi_1, \varpi_2)) \tag{6.2}$$

$$A_1 - A_2 = (a_1, b_1, c_1, d_1; \varpi_1) + (a_2, b_2, c_2, d_2; \varpi_2)$$

$$(a_1 - d_2, b_1 - c_2, c_1 + b_2, d_1 - a_2; \min(\varpi_1, \varpi_2)) \tag{6.3}$$

$$A_1 + A_2 = (a_1, b_1, c_1, d_1; \varpi_1) + (a_2, b_2, c_2, d_2; \varpi_2)$$

$$(a_1 + a_2, b_1 + b_2, c_3 \times c_3, d_4 \times d_4; \min(\varpi_1, \varpi_2)) \tag{6.4}$$

$$A_1 / A_2 = {}^{(a_1, b_1, c_1, d_1; \varpi_1)}\!\big/_{(a_2, b_2, c_2, d_2; \varpi_2)}$$

$$= (a_1 / d_2, b_1 / c_2, c_1 / b_2, d_1 / a_2; \min(\varpi_1, \varpi_2)) \tag{6.5}$$

6.5 Ranking of Generalized Trapezoidal Fuzzy Numbers: The Revised Ranking Method

The concept of '*Maximizing set and Minimizing set*' for fuzzy numbers ranking as proposed by (Chou et al., 2011) has been adopted here. The revised ranking method as proposed by (Chou et al., 2011) is as follows:

Suppose there are n generalized fuzzy numbers $A_i = [a, b, c, d; w_i]$. $i = 1, 2 \ldots\ldots\ldots \ldots n$, each with a trapezoidal membership function

$$f_A(x)=\begin{cases}\dfrac{x-a_i}{b_i-a_i}\times w_i, & x\in(a_i\le x\le b_i,)\\ \varpi_i, & x\in(b_i,\le x\le,c_i)\\ \dfrac{x-d_i}{c_i-d_i}\times w_i, & x\in(c_i,\le x\le,d_i)\\ 0, & otherwise,\end{cases} \qquad (6.6)$$

For each pair of Generalized Fuzzy Numbers set, say A_1 *and* A_2 the pair wise comparison is preceded as follows. The maximizing set M and minimizing set G have membership functions f_M, f_G are given respectively as

$$f_M(x)=\begin{cases}\dfrac{x-x_{\min}}{x_{\max}-x_{\min}}\times w_i, & (x_{\min}\le x\le x_{\max})\\ 0, & otherwise,\end{cases} \qquad (6.7)$$

and

$$f_G(x)=\begin{cases}\dfrac{x_{\max}-x}{x_{\max}-x_{\min}}\times w_i, & (x_{\min}\le x\le x_{\max})\\ 0, & otherwise,\end{cases} \qquad (6.8)$$

where, $x_{\min}=\inf S$, $x_{\max}=\sup S$, $S=U_{i=1}^{n}S_i$, $S_i=\{x/\,f_{A_I}(x)\succ 0\}$, $w_i=\sup_x f_{A_I}(x), w=\inf w_{i.}$

The revised ranking method defines the right and left utility values of each generalized fuzzy number A_i as

$$u_{M_{I1}}(i)=\sup_x f_M(x)\wedge f_{A_i^R}(x)),\quad i=1,2, \qquad (6.9)$$

$$u_{G_{I2}}(i)=\sup_x f_G(x)\wedge f_{A_i^R}(x)),\quad i=1,2, \qquad (6.10)$$

$$u_{G_{I1}}(i)=\sup_x f_G(x)\wedge f_{A_i^R}(x)),\quad i=1,2, \qquad (6.11)$$

$$u_{M_{I2}}(i)=\sup_x f_M(x)\wedge f_{A_i^R}(x)),\quad i=1,2, \qquad (6.12)$$

The revised ranking method defines the total utility value of each Generalized Fuzzy Number set A_i as

$$u_T^{\alpha}(i)=\frac{\{\alpha[u_{M_{i1}}(i)+ww_i-u_{G_{i2}}(i)]+(1-\alpha)[(u_{M_{i2}}(i)+ww_i-u_{G_{i2}}(i)+w-u_{G_{i1}}(i)]\}}{2},\ i=1,2. \qquad (6.13)$$

Then,

$$u_{M_{i1}} = \frac{ww_i(d_i - x_{\min})}{w(d_i - c_i) + w_i(x_{\max} - x_{\min})}, \tag{6.14}$$

$$u_{G_{i1}} = \frac{ww_i(x_{\max} - a_i)}{w(b_i - a_i) + w_i(x_{\max} - x_{\min})}, \tag{6.15}$$

$$u_{M_{i2}} = \frac{ww_i(a_i - x_{\min})}{w(a_i - b_i) + w_i(x_{\max} - x_{\min})}, \tag{6.16}$$

$$u_{G_{i2}} = \frac{ww_i(x_{\max} - d_i)}{w(c_i - d_i) + w_i(x_{\max} - x_{\min})}, \tag{6.17}$$

and the total utility value is

$$u_T^{\alpha}(i) = \frac{ww_i}{2}\left(\begin{array}{l} \alpha\left[\dfrac{(d_i - x_{\min})}{w(d_i - c_i) + w_i(x_{\max} - x_{\min})} + \dfrac{1}{w_i} - \dfrac{(x_{\max} - d_i)}{w(c_i - d_i) + w_i(x_{\max} - x_{\min})}\right] + \\ (1-\alpha)\left[\dfrac{(a_i - x_{\min})}{w(a_i - b_i) + w_i(x_{\max} - x_{\min})} + \dfrac{1}{w_i} - \dfrac{ww_i(x_{\max} - a_i)}{w(b_i - a_i) + w_i(x_{\max} - x_{\min})}\right] \end{array} \right) \tag{6.18}$$

The greater the $u_T^{\alpha}(A_i)$, the bigger the fuzzy number A_i and the higher it's ranking order.

Using Eq. 6.18, the ranking value of each generalized trapezoidal fuzzy number set A_i with trapezoidal membership function can be calculated quickly.

The revised ranking method defines the total utility value of each fuzzy number A_i with index of optimism (α) as:

$$u_T^{\alpha}(i) = \alpha\left[\alpha\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\} + (1-\alpha)\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\}\right], \ 1,2. \tag{6.19}$$

The index of optimism (α) represents the degree of optimism of a decision-maker (Chou et al., 2011). A larger (α) indicates a higher degree of optimism. More specifically, when $\alpha = 0$, the total utility value $u_T^0(A_i)$ representing a pessimistic decision-makers view point is equal to the total left utility value of A_i. It represents the rough point of view of decision-makers.

Conversely, for optimistic decision-makers, i.e. $\alpha = 1$, the total utility value $u_T^1(A_i)$ is equal to the total right utility value of A_i. It represents the appropriate point of view of decision-makers. For a moderate (neutral) decision-maker, i.e. α = 0.5, the total utility value of each fuzzy number A_i become

$$u_T^{1/2}(i)=\frac{1}{2}\left[\frac{1}{2}\{u_{M_{i1}}(i)+1-u_{G_{i2}}(i)\}+\frac{1}{2}\{u_{M_{i2}}(i)+1-u_{G_{i1}}(i)\}\right],\ 1,2. \tag{6.20}$$

It represents the moderate point of view of decision-makers. The greater the $u_T^{\alpha}(A_i)$, the bigger the fuzzy number A_i and the higher its ranking order.

6.6 Proposed Fuzzy Based Resilience Appraisement Module: Case Research

In this work, a case research has been conducted to verify application credentials of the proposed approach in order to evaluate an overall resilience index of the particular supply chain and to identify ill-performing areas of the said supply chain in relation to the candidate industry under consideration.

The proposed appraisement module has been case studied in a famous automobile part manufacturing industry located at eastern part of India. In the primary stage, after extensive literature review and periodic group discussions with the industry's top management, an integrated hierarchy model towards assessment of ongoing performance of the resilient supply chain, has been constructed and made for ready to be case studied. The model encompasses of resilient criterions (performance indicators).

From this perspective, a three-layer hierarchical framework for SC resilient performance evaluation module has been constructed [Christopher and Peck (2004a, b); Lin et al., (2006); Vilko and Hallikas (2012); Bolden et al.,(2003); Williams et al., (2013); Hao et al. (2012); Shih et al., (2012); Vlajic et al.,(2012);Young and Samson (2008)]; as revealed in Tables 6.1.1-6.1.2.

The three-layer hierarchical module encompasses several evaluation indices in which supply chain re-engineering (C_1), Supply chain collaboration (C_2), Create a supply chain risk management culture (C_3), Agility (C_4) have been considered as the main indices at 1st layer followed by 2nd as well as 3rd layer, encompasses different resilient initiatives/indices.

An evaluation team consisting of five experts has been deployed to assign priority weights (importance extent) against different criterions (indicators of resilient performance) considered in the proposed appraisement model. A questionnaire has been formed and circulated among the decision-makers (experts) to provide the required detail. Several brainstorming sessions have been conducted to finalize a concrete criteria hierarchy to be explored. Secondly, the expert group has been instructed to assign priority importance (weights) as well as appropriateness rating (performance extent) against individual evaluation indices based on a predetermined linguistic scale. In this context, the decision-making group has been requested to visit the candidate industry in order to investigate (inspect) every internal and external system/sub-system of the industrial supply chain from the perspective of assessing supply chain resiliency against probable external as well as internal disturbances.

In this case research, it has been assumed that a committee of five decision-makers (expert panel) such as $\left(DM_1, DM_2, DM_3, DM_4, DM_5\right)$ has been constructed consisting of members like management consultant/practitioner as well as academician. In this case study, priority weights against individual indices and corresponding performance extent (appropriateness rating) provided by the expert group expressed in linguistic terms; have been further transformed into (Generalized Trapezoidal Fuzzy Number set) GTFNs (Table 6.2).

A 5-member linguistic term set [Very Low (L), Low (L), Medium (M), High (H) and Very High (VH)] have been utilized for the assessment of appropriateness rating against individual 3rd level evaluation indices. Similarly, another 5-member linguistic term set [Unimportant (UI), Moderately Important (MI), Important (I), Very Important (VI) and Absolutely Important (AI)] have been explored to assign priority weights of various evaluation indices starting from 1st level to the 3rd level of the criteria hierarchy. Then, application of fuzzy operational rules have been carried out to analyze subjective human judgment in order to obtain a qualitative resiliency metric (Fuzzy Performance Index; FPI) of the organizational supply chain. The procedural steps of the proposed SC resilience evaluation platform followed by results of empirical data analysis have been summarized below.

Step 1: Collection of expert judgment (linguistic assessment) against individual evaluation indices

In order to collect expert opinion (in the form of linguistic assessment) against individual evaluation indices; a committee of fives decision-makers: $DM_1, DM_2, DM_3, DM_4, DM_5$ have been constructed. The team members have been requested to express their subjective preferences (evaluation score) through linguistic terminology towards assigning priority weights (for 1st, 2nd and 3rd level indices) as well as appropriateness rating against individual 3rd level performance indices depicted in Table 6.1.1. Decision-Makers' linguistic preferences have been transformed into appropriate Generalized Trapezoidal Fuzzy Number (GTFN) set in accordance with the scale as chosen Table 6.2. The linguistic data, in relation to priority weight as well as appropriateness rating against several indices assessed by the group decision-makers (DMs) have been revealed in Tables 6.3-6.4.

Step 2: Approximation of the linguistic evaluation information by GTFNs set theory

By employing the concept of Generalized Trapezoidal Fuzzy Number (GTFN) set in fuzzy set theory; the linguistic variables have been transformed into appropriate fuzzy numbers as prescribed in Table 6.2. Next, based on 'fuzzy average' rule; the aggregated priority weights and aggregated fuzzy appropriateness rating against individual 3rd level evaluation indices have been obtained (Table 6.5). Similarly, aggregated priority weight of different evaluation indices (at 2nd and 1st level) have been obtained and presented in (Tables 6.6-6.7).

Following the backward path (starting from 3rd level to the preceding levels in the evaluation hierarchy); and by exploring 'fuzzy weighted average' rule; computed appropriateness rating against different evaluation indices at 2nd and finally 1st level have been obtained and revealed in (Tables 6.6-6.7).

Computed appropriateness rating for each of the 2nd level evaluation index U_{ij} (rating of j_{th} 2nd level index, which is under i_{th} 1st level index) has been obtained as follows:

$$U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ijk}} \tag{6.21}$$

In this expression (Eq. 6.21), U_{ijk} is denoted as the aggregated fuzzy appropriateness rating and w_{ijk} be the aggregated fuzzy importance weight against k_{th} index (at 3rd level) which is under j_{th} index in the 2nd level and under i_{th} index in the 1st level..

Appropriateness rating for each of the 1st level evaluation index U_i (rating of i_{th} index) has been computed as follows:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{6.22}$$

In this expression (Eq. 6.22), U_{ij} is denoted as the computed fuzzy appropriateness rating (resulted by Eq. 6.21) against j_{th} index (at 2nd level) which is under i_{th} index in the 1st level. Also w_{ij} is the aggregated fuzzy weight against j_{th} index (at 2nd level) which is under i_{th} index at 1st level.

Step 3: Estimation of Fuzzy Performance Index (FPI)

Then fuzzy performance index (FPI) (of the resilient SC) has been computed by employing Eq. 6.23. In this expression, U_i is denoted as computed fuzzy appropriateness rating (resulted by Eq. 6.22) against i_{th} index (at 1st level). Also w_i is the aggregated fuzzy weight against i_{th} index at 1st level.

$$FPI = \frac{\sum U_i \otimes w_i}{\sum w_i} \tag{6.23}$$

The overall Fuzzy Performance Index (FPI) thus computed as OFPI: **(0.0373, 0.3104, 1.2021, 11.011; 0.6)** representing resilience extent of the said supply chain under consideration. The FPI can be compared with predefined or standard fuzzy resilience assessment scale set by the top management of the enterprise to check and compare existing resilience level to identify ill (week) performing areas of SC network elements which require subsequent future improvement.

Step 4: Computation of Fuzzy Performance Importance Index (FPII): Identification of ill-performing areas

After evaluating FPI, the next step is to identify and analyze ill-performing areas of the SC in view of SC resilience performance. For this the concept of Fuzzy Performance Importance Index (FPII) can be fruitfully explored. The concept of computing FPII has been reported by (Lin et al., 2006) which combines performance rating and importance weight of different evaluation indices at 3rd level. The higher the FPII of a factor (evaluation index), the higher is the contribution towards SC resilience.

$$FPII_{ijk} = w'_{ijk} \times U_{ijk} \tag{6.24}$$

$$w'_{ijk} = [[(1,1,1,1;1)] - w_{ijk}] \quad (6.25)$$

U_{ijk} is the aggregated fuzzy appropriateness rating and w_{ijk} is the aggregated fuzzy importance weight of k_{th} 3rd level index which is under j_{th} 2nd level index and under i_{th} 1st level evaluation index.

If, we directly calculate FPII; the importance weights w_{ijk} will neutralize the performance ratings in computing FPII; in this case, it will become impossible to identify the actual weak performing areas (*low performance rating and high importance*). If, w_{ijk} is high, then the transformation $[(1,1,1,w_{ijk}) - w_{ijk}]$ is low. Consequently, to elicit a factor with low performance rating and high importance weights, for each resilient initiative C_{ijk}, the fuzzy performance importance index $FPII_{ijk}$, resulted $FPII_{ij} = [(1,1,1,w_{ijk}) - w_{ijK}] \otimes U_{ijk}$.

By exploring the concept of fuzzy numbers ranking by '*Maximizing Set and Minimizing Set*', FPIIs against each of the 3rd level resiliency criterions have been transformed into total utility value u_T^{α}. This total utility value being a crisp one, it becomes easy to rank various resiliency criterions (at 3rd level) based on their performance. In this analysis, decision-makers' risk bearing attitude plays an important role. Therefore, the (Eq. 6.24) has been employed towards evaluating and assessing the resilient supply chain ill/weak performing indices (through criteria ranking) of preferred candidate enterprise. Therefore, the appraisement, raking order and identification of resilience barriers conveyed in accordance with descending value of utility at $(\alpha = 0, 0.5, 1)$ revealed in (Table 6.8, Fig. 6.2). Higher value of 'utility' reflects strong performance extent.

For optimistic decision-maker, $\alpha = 1$; for a moderate (neutral) decision-maker, α = 0.5; and for pessimistic decision-maker, $\alpha = 0$. In Fig. 6.2, the horizontal axis represents various 3rd level resilience indices and vertical axis represents overall utility value against individual 3rd level indices for three different types of decision-making group (for optimistic, moderate and pessimistic decision-maker). Higher utility indicates higher level of performance. Thus resiliency criterions could be ranked (in view of ongoing performance extent) by which ill-performing areas could easily be identified. Industry should think of future action plans in order to overcome those barriers and consequently to improve overall supply chain's resilience performance.

6.7 Managerial Implications

In today's competitive global marketplace, a number of supply chain networking strategies (i.e. leanness, agility, le-agility alliance, flexibility etc.) have fruitfully been implemented towards fulfilling unpredictable market demand, ensuring consumer satisfaction and response, improved product quality and various other business goals. In addition to the existing SC strategies, supply chain resilience has been understood as a winning initiative of SCM which is concerned with the system ability to return its present state to the primitive one or to a particular state, more desirable, after experiencing a disturbance and avoiding the occurrence of failures modes (Cabral et al., 2011). Sustainable resiliency grows winning environment in the enterprise and even creates a positive image in people's brain and hold the collaborated contractor and dealers with candidate industry. From this viewpoint, it has become indeed necessary to facilitate industry managers to evaluate, check and compare overall supply chain resilient performance based on a prescribed set of resilience criteria hierarchy; and also to investigate on the weak/ill performing areas of the SC network for effective management, reformation, amendment and subsequent future improvement.

In this context, the manager has to adapt and implement the proposed resilient supply chain multi-layer evaluation platform in which resilient performance appraisement is based upon subjective assessment (linguistic judgment) of expert's panel which is further transformed into appropriate Generalized Triangular Fuzzy Numbers (GTFNs) prescribed in the predefined fuzzy scale. The concept of fuzzy numbers ranking by revised ranking method (Chou et al., 2011) exploring '*Maximizing set and Minimizing set theory*' has been articulated here towards identifying ill-performing resilience criterions in relation to the candidate enterprise.

This multi-layer appraisement evaluation framework (basically a Decision Support System) could be helpful for the managers, whenever, they plan to implement such an appraisement framework over the preferred candidate industry and the decision could be based on the evaluated group decision-makers' subjective assessment.

6.8 Concluding Remarks

In the aforesaid work, a hierarchical appraisement framework aligned with a multiple indices (performance evaluators) of resilient supply chain networking, has been proposed. Fuzzy set theory has been fruitfully applied in pursuit of estimating overall SC resilient extent.

The main contributions of the aforesaid research have been highlighted below.

1. Effective exploration of fuzzy set theory: Proposed hierarchical appraisement index system (module) has the capability to tackle inherent vagueness, impreciseness, inconsistency and ambiguity entitled in evaluated subjective information provided by the decision-makers.
2. Exploration of revised ranking method of generalized fuzzy numbers using '*Maximizing set and Minimizing set*' towards finding weak/ill performing areas/initiatives of the SC in perspective of overall resilient performance of the candidate industry under consideration.
3. This methodology might be successfully applied to help other decision making problems from the perspective of performance appraisal and benchmarking of candidate alternatives/choices under predefined criteria and subjective evaluation circumstances.

Table 6.1.1: Supply chain resilient performance appraisement module (evaluation framework)

Goal	1st level indices (C_i)	2nd level indices (C_{ij})	3rd level indices (C_{ijk})
Resilient Performance Extent	Supply chain re-engineering, (C_1)	Supply chain design principle, ($C_{1,1}$)	Extent of real option thinking, ($C_{1,1,1}$)
			Efficiency vs redundancy, ($C_{1,1,2}$)
			Increased preparedness to disturbances, ($C_{1,1,3}$)
			Creation of an adaptive supply chain community, ($C_{1,1,4}$)
			Use of technical solutions to deal with disturbance, ($C_{1,1,5}$)
		Supply chain understanding, ($C_{1,2}$)	Supply chain risk registering, ($C_{1,2,1}$)
			Mapping critical path analysis, ($C_{1,2,2}$)
		Supply base strategy, ($C_{1,3}$)	Sourcing decision criterion, ($C_{1,3,1}$)
			Supplier development, ($C_{1,3,2}$)
	Supply chain collaboration, (C_2)	Collaborative planning, ($C_{2,1}$)	Material planning, ($C_{2,1,1}$)
			Production planning, ($C_{2,1,2}$)
			Inventory planning, ($C_{2,1,3}$)
			Distributor inventory planning, ($C_{2,1,4}$)
		Supply chain intelligence, ($C_{2,2}$)	Extent of online discussion, ($C_{2,2,1}$)
			Effective handling of question and answer, ($C_{2,2,2}$)
			Information discovery, ($C_{2,2,3}$)
			Decision-coordination, ($C_{2,2,4}$)
			Business intelligence, ($C_{2,2,5}$)
			Issue-based argumentation, ($C_{2,2,6}$)
	Creating a supply chain risk management culture, (C_3)	Establish supply chain continuity teams, ($C_{3,1}$)	Cross functional integration, ($C_{3,1,1}$)
			Autonomous team structure, ($C_{3,1,2}$)
			Team experience, ($C_{3,1,3}$)
			Team continuity, ($C_{3,1,4}$)
			Efficient office designed for communication, ($C_{3,1,5}$)
		Broad level responsibility and leadership, ($C_{3,2}$)	Clear task defining, ($C_{3,2,1}$)
			Make the plan, ($C_{3,2,2}$)
			Effective control of quality and rate of work, ($C_{3,2,3}$)
			Ensure communication within group, ($C_{3,2,4}$)
			Encourage, motivate, give a sense of purpose, ($C_{3,2,5}$)
			Check performance against plan, ($C_{3,2,6}$)
			Managing financial crisis, ($C_{3,3,1}$)

		Factor risk consideration into decision making, ($C_{3,3}$)	Organization's financial risk , ($C_{3,3,2}$)
			Extent of outside interference in the SC, ($C_{3,3,3}$)
			Carelessness and a lack of motivation among the workforce, ($C_{3,3,4}$)
			Problems with customs clearance, ($C_{3,3,5}$)
			Interpretation problems with documents, contracts and permits, ($C_{3,3,6}$)
	Supply Chain Agility, (C_4)	Agility in visibility, ($C_{4,1}$)	Demand visibility, ($C_{4,1,1}$)
			Supply chain visibility, ($C_{4,1,2}$)
			Market visibility, ($C_{4,1,3}$)
		Agility capabilities, ($C_{4,2}$)	Responsiveness, ($C_{4,2,1}$)
			Competency, ($C_{4,2,2}$)
			Flexibility, ($C_{4,2,3}$)
			Quickness, ($C_{4,2,4}$)

Table 6.1.2: Definitions/explanations of individual performance indices of resilient supply chain

1st Level Indices (C_i)	Definition/ Explanation	References/Citation
Supply chain re-engineering	Supply chain re-engineering is the analysis, re-creation and modification of existing configuration of the supply chain.	[Source: Sweeney (2000)]
Supply chain collaboration, (C_2)	It is an interaction supported by technology between two or more parties which play a vital role in the supply chain in perceptive to achieve a common goal and mutual benefit.	[Source: http://www.slideshare.net/NicolasCasa/what-is-supply-chain-collaboration]
Create a supply chain risk management culture, (C_3)	It is creation of the supply chain risks management culture through coordination or collaboration among the supply chain partners in perceptive to ensure profitability and continuity of enterprises.	[Source: Levy (2008), Tang (2006b)]
Agility, (C_4)	Agility refers to novel ways of running companies to react quickly and effectively against changing markets, driven by customized products and services.	[Source: Lin et al, (2006)]
2nd Level Indices (C_{ij})	Definition/ Explanation	References/Citation
Supply chain design principle, ($C_{1,1}$)	Supply chain design principle focuses on the culture of working together which enhances revenue, cost control, asset utilization as well as customer satisfaction against disturbances/vulnerabilities.	[Source: www.supplychainventure.com/.../thesevenprinciplesofsupplychainmanView shared post]

Supply chain understanding, ($C_{1,2}$)	It is a fundamental pre-requisite for making out the supply chain network that connects the business to its suppliers and their suppliers to its downstream customers for improving supply chain resilience.	[Source: Christopher and Peck (2004b)]
Supply base strategy, ($C_{1,3}$)	It may be defined as a design and planning strategy against supply base (vendor) in order to meet customer demand at the lowest possible cost under uncertainty and disturbances.	[Source: http://www.lcpconsulting.com/services/end-to-end-expertise/supply-chain-strategy] and [Source: Christopher and Peck (2004b)]
Collaborative planning, ($C_{2,1}$)	The process through which a firm works together with its suppliers and customers in perspectives to design and forecast demand for next products.	[Source: http://www.integratedtransportllc.com/transportation-trucking-glossary]
Supply chain intelligence, ($C_{2,2}$)	Supply chain intelligence is the convergence of supply chain management and business intelligence. It is the capability to access, integrate, analyze and share information across and beyond the enterprise. The key to this is the analytic application: software designed exclusively for supply chain processes including procurement, manufacturing as well as distribution.	
Broad level responsibility and leadership, ($C_{3,2}$)	Leadership is considered as one of the most essential aspects supported by hierarchical team efforts to corporate and manage supply chain networking and activity in the firm. Leadership develops the prescribed liability for each individual manager at hierarchy line of the company to achieve business excellence.	[Source: http://www.buzzle.com/articles/leadership-roles-and-responsibilities.html]
Factor risk consideration into decision making, ($C_{3,3}$)	It may be defined as a consideration of different aspects of risk against the formulated problem during the decision making process. The risk management consideration into decision making process is associated with five steps: (1) identify loss exposures (2) examining alternative risk management tool/technique/decision support system for dealing with chosen exposure (3) selecting the best tool/technique/decision support system (3) implementing the chosen technique (5) monitoring the consequence of adopted technique to ensure their effectiveness.	[Source: http://onlinelibrary.wiley.com/doi/10.1002/jhrm.5600080305/abstract]
Establish supply chain continuity teams, ($C_{3,1}$)	It refers to continuous establishment of supply chain teams to effectively improve and manage organizational effectiveness over whole supply chain and their key areas.	[Source: http://www.pmi.com/eng/careers/our_people/operations/pages/supply_chain_team.aspx and http://supplychainsystems.com/portfolio/supply-chain-team-dev/]
Visibility, ($C_{4,1}$)	It is the ability of parts, components or products in transit to be tracked from	[Source:

	the manufacturer to their final destination. The goal of supply chain visibility is to improve and strengthen the supply chain by making data readily available to all stakeholders, including the customer.	http://searchmanufacturingerp.techtarget.com/definition/supply-chain-visibility-SCV]
Agility capabilities, ($C_{4,2}$)	It is the capability of enterprises to rapidly change or adapt in response to changes in the market. High organizational agility capability supports to enterprises for successful survival against emergence of novel competitors, the development of new industry-changing technologies, or sudden shifts in overall market conditions.	[Source: http://www.businessdictionary.com/definition/organizational-agility.html]
3rd Level Indices (C_{ijk})	Definition/Explanation	References/Citation
Material planning,($C_{2,1,1}$)	It is a part of production planning and inventory control system; being explored to manage manufacturing processes. Most of the material planning systems is software-based, whereas, it is possible to conduct MRP (Material Requirement Panning) by hand as well.	[Source: http://www.princeton.edu/~achaney/tmve/wiki100k/docs/Material_Requirements_Planning.html]
Production planning, ($C_{2,1,2}$)	It refers to the estimation of the resources which are required to achieve organization's unified goals. It prepares a detailed plan for achieving the production goals economically, efficiently and within scheduled time span.	[Source: http://kalyan-city.blogspot.com/2012/01/what-is-production-planning-meaning.html]
Inventory planning, ($C_{2,1,3}$)	The refers to evaluation and estimation of optimal inventory quantity necessary to compensate sales and production capacity in confined time. Inventory planning has a direct impact a company's cash flow and profit margins especially for smaller businesses that rely upon a quick turnover of goods or materials.	[Source: http://www.businessdictionary.com/definition/inventory-planning.html]
Distributor inventory planning, ($C_{2,1,4}$)	It is a method used in business administration for planning orders within a supply chain. DIP enables the user to set certain inventory control parameters (like safety stock) and calculates the time-phased inventory requirements. This process is also commonly referred to as distribution requirements planning.	[Source: http://en.wikipedia.org/wiki/Distribution_resource_planning]
Demand visibility, ($C_{4,1,1}$)	It is strategies provide the ability to obtain relevant information about the product at the appropriate time to enable decisions with a high degree of confidence based on the analysis of contemporary data.	[Source: http://www.cmoleadershipawards.com/index.php/en/articles/53-articles-2012/57-implementing-on-demand-visibility-to-improve-outcomes]
Supply chain visibility, ($C_{4,1,2}$)	It is the ability of an organization to analyses and visualizes customers' expectations which are necessity in pursuing business in global market.	[Source: searchmanufacturingerp.techtarget.com/definition/supply-chain]
Market visibility, ($C_{4,1,3}$)	It refers to the activities including budget versus actual spend, understanding	[Source:

	of type of activity in-market and subsequent planning, identification and removal of bottlenecks, improving overall speed to market.	http://www.orbisglobal.com/Marketing-Management-Resources/marketing-systems-for-the-enterprise-streamlining-marketing-processes-to-achieve-end-to-end-marketing-visibility/]
Responsiveness, ($C_{4,2,1}$)	It may be defined as the specific ability of a system or functional unit to complete assigned tasks within an allowable time. There are many factors that can influence the responsiveness of an interaction system, such as poor design, improper input from users, problems with the operation system or the network.	[Source: http://en.wikipedia.org/wiki/ResponsivenessView shared post]
Competency, ($C_{4,2,2}$)	It is basically cluster related abilities like commitments, knowledge, and skills that enable an enterprises to act or manage effectively in a business or situation.	[Source: http://www.businessdictionary.com/definition/competence.html]
Flexibility, ($C_{4,2,3}$)	It is the ability of enterprises to cost effectively vary its output within a certain range and given time frame.	[Source: http://www.businessdictionary.com/definition/flexibility.html]
Quickness, ($C_{4,2,4}$)	It may be defined as an ability to deliver correct responses without delay.	[Source: http://www.thefreedictionary.com/quickness]
On-line discussion,($C_{2,2,1}$)	It is a relatively novel form of communication, facilitated usually by computer networks. The first such communications were on mainframe-based systems such as the PLATO and CONFER systems.	[Source: http://en.wikipedia.org/wiki/Online_discussion]
Question and answer,($C_{2,2,2}$)	It refers to an expression of inquiry that invites or calls for a reply an answer from the prospectus of seeking the avenue of a specific problem.	[Source: http://www.thefreedictionary.com/question]
Information discovery,($C_{2,2,3}$)	It refers to the searching of enterprise data or digital information such as email, files and other data while organizations need information for making business decisions or other perspectives.	[Source: http://www.webopedia.com/TERM/E/e_discovery.html]
Decision-coordination,($C_{2,2,4}$)	It may be defined as the collaboration/interaction of personnel/employees of different department for making effective decisions about a specific problem in an organization.	[Source: https://www.google.co.in/#q=definition+of+coordination] and the action or process of making important decisions]
Business	Technological applications for gathering, storing, analyzing and providing	[Source:

intelligence,($C_{2,2,5}$)	access to the data base (information) for helping enterprise users to make better business decisions.	http://searchdatamanagement.techtarget.com/definition/business-intelligence]
Issue-based argumentation,($C_{2,2,6}$)	It is an act or process of forming reasons and of drawing conclusions/avenue on an essential point.	[Source: http://www.merriam-webster.com/dictionary/argumentation] and http://www.thefreedictionary.com/issue]
Cross functional integration, ($C_{3,1,1}$)	The magnitude of interaction and communication, the level of information sharing, the degree of coordination and the extent of joint involvement across functions for specific tasks.	[Source: http://en.wikibooks.org/wiki/Handbook_of_Management_Scales/Cross-functional_integration]
Autonomous team structure, ($C_{3,1,2}$)	It refers to assembling/assigning a team of employees for a specific task under the action of the product manager. The team is thus temporary and may be disbanded when its task is complete.	[Source: http://www.zarate-consult.de/kosvet3/m4/keet_m4_lu5_l3/project_team_structure.html] and https://www.google.co.in/search?q=autonomous+team+structure&tbm=isch&tbo=u&source=univ&sa=x&ei=ferjur_7kovlrqepnocqdg&sqi=2&ved=0cdsqsaq&biw=1366&bih=615]
Team experience, ($C_{3,1,3}$)	It represents the accumulation of knowledge or skill of team employees for the assigned task that they obtained from previous organization/task.	[Source: http://www.thefreedictionary.com/experience]
Team continuity, ($C_{3,1,4}$)	It refers to the ability of team members (employee/workers) to convey the assigned task up to end under scheduled period of time for specific business project and the team will continue as long as without rotation.	[Source: http://codebetter.com/jeremymiller/2006/05/06/want-productivity-try-some-team-continuity-and-a-side-of-empowerment-too/]
Office designed for communication, ($C_{3,1,5}$)	It refers to align all re-creation and modification aspects pertaining office layout or office space that satisfy employee duties beyond the imparting or exchanging of information by speaking, writing, or using some other medium.	[Source: http://en.wiktionary.org/wiki/communication] and [Source: http://en.wikipedia.org/wiki/Office_design]
Define the task, ($C_{3,2,1}$)	It is an activity which is supported by responsible employees within a defined period of time.	[Source: http://en.wikipedia.org/wiki/Task_(proj

		ect_management]
Make the plan, ($C_{3,2,2}$)	It is a formal statement of a set of business goals. It encompasses background information to make the enterprises or team attempting to obtain those goals and constrained objectives.	[Source: http://en.wikipedia.org/wiki/Business_plan]
Control quality and rate of work, ($C_{3,2,3}$)	Control quality indicates set of procedures intended to ensure that a manufactured product or performed service adheres to a defined set of quality criteria or meets the requirements of the customer. Control rate of work refers to the easiness of controlling the degree of speed, progress, working time against an assigned task to employees as well as workers.	[Source: http://whatis.techtarget.com/definition/quality-control-QC and [http://dictionary.reference.com/browse/rate]
Ensure communication within group, ($C_{3,2,4}$)	It refers to the communication between a group of employees and another group of employees or within the group itself to obtain the solution of a specific problem.	[Source: http://www.ask.com/question/what-is-the-meaning-of-group-communication]
Encourage, motivate, give a sense of purpose, ($C_{3,2,5}$)	It means that encouragement and motivation shall accumulate the employee's knowledge and skill to lay out the assigned task towards successful completion.	[Source: http://answers.yahoo.com/question/index?qid=20100705092153AATs9hi]
Check performance against plan, ($C_{3,2,6}$)	It indicates the assessment and evaluation of organizational performance against the set/prescribed/targeted business goal and constrained objectives.	[Source: http://en.wikipedia.org/wiki/Business_plan] and [Source: http://betterevaluation.org/theme/organizational_performance]
Financial Crisis, ($C_{3,3,1}$)	It deals with situations in which some financial assets suddenly lose a large part of their nominal value in an organization.	[Source: http://en.wikipedia.org/wiki/Financial_crisis]
Organization's financial risk , ($C_{3,3,2}$)	It may be defined as a risk incurred by an organization in the view of possible monitory loss.	[Source: http://www.investopedia.com/terms/f/financialrisk.asp]
Outside interference in the SC, ($C_{3,3,3}$)	It explains the leverage of outside unwanted event/disturbance/disaster over either upstream or downstream supply chain. These are associated the high demand fluctuation, any disturbances to the flow of product, environment disturbance (storm, quake), physical risks (condition of supplier's physical facilities).	[Source: Christopher and Peck (2004a)]
Carelessness and a lack of motivation among the	It is concerned with the consciousness and self-motivation of the group of workers towards completion of a specific project or activity/task under the	[Source: http://en.wikipedia.org/wiki/Carelessn

workforce, ($C_{3,3,4}$)	scheduled time.	ess] and [Source: http://www.thefreedictionary.com/workforce]
Problems with customs clearance, ($C_{3,3,5}$)	Custom clearance refers to the examination and assessment of prepared and submitted document of consignment in order to export or imports it out of country.	[Source: http://www.universalcargo.com/blog/bid/95413/what-is-customs-clearance]
Supply chain risk register, ($C_{1,2,1}$)	It is an open vocabulary of organizational risk ensuring the stakeholder about the present status of the organization at any point in time. A risk register as part of the risk management helps to make out the nature of the risks of the organization, become aware of the extent of those risks, identify both the level of risk that the organization's management is willing to accept and the level of risk that the organization itself is willing to accept, recognize its ability to control and reduce risk, report the risk status at any point in time.	[Source: http://www.roughnotes.com/rnmagazine/2013/january/2013_01p034.htm]
Mapping critical path analysis, ($C_{1,2,2}$)	The mapping critical path refers to the analysis/measurement of those activities/events/tasks which are assigned to be completed on/in scheduled time.	[Source: http://www.investopedia.com/terms/c/critical-path-analysis.asp]
Sourcing decision criterion, ($C_{1,3,1}$)	It refers to the procurement practices, evaluating and engaging supplier's goods and services criterions in decision making scenario.	[Source: http://en.wikipedia.org/wiki/Sourcing]
Supplier development, ($C_{1,3,2}$)	It is the process of working with certain suppliers on a one-to-one basis to improve their performance (capabilities) for delivering the benefit to product purchasing parties.	[Source: http://cipsintelligence.cips.org/opencontent/cips-purchasing-supply-management.-supplier-development]
Real option thinking, ($C_{1,1,1}$)	It may be defined as the consideration and evaluation of alternatives or choice/option from business investment opportunity perspective.	[Source: http://www.investopedia.com/terms/r/realoption.asp]
Efficiency vs. redundancy, ($C_{1,1,2}$)	Efficiency is the way a company overhauls its procedures and policies to meet or exceed organization goals. Redundancy refers to provision or existence of more than one resource in an organization for performing an activity/task or function well.	[Source: http://www.ask.com/question/organizational-efficiency] and http://www.oxfordshire.gov.uk/cms/content/redundancy-or-efficiency]
Increase preparedness to disturbances, ($C_{1,1,3}$)	It is a process of ensuring an organization (1) has complied with the preventive measures, (2) is in a state of readiness to contain the effects of a forecasted disastrous event to minimize loss of life, injury, and damage to property, (3) can provide rescue, relief, rehabilitation, and other services in the aftermath of the disaster, and (4) has the capability and resources to continue to sustain its essential functions without being overwhelmed by the demand	[Source: http://www.businessdictionary.com/definition/disaster-preparedness.html]

	placed on them, etc.	
Create an adaptive supply chain community, ($C_{1,1,4}$)	It is the involvement of government, industry, nonprofit association and institutions to tackle handle and overcome the disaster/disturbances.	
Use of technical solutions to deal with disturbance, ($C_{1,1,5}$)	It refers to the usage of technical tool and technological supportive system to handle, tackle, and overcome occurred disturbance/disasters.	[Source: http://www.thefreedictionary.com/disturbance]

Table 6.2: Definitions of linguistic variables for assignment of criteria ratings as well as priority importance along with fuzzy representation
[Source: Yu et al., 2013]

Priority Rating		Priority weights	
Very low (VL)	(0.000,0.100,0.200,0.300;0.600)	Unimportant (UI)	(0.000,0.200,0.300,0.400;0.600)
Low (L)	(0.100,0.100,0.450,0.700;0.700)	Moderately Important (MI)	(0.200,0.400,0.500,0.600;0.700)
Medium (M)	(0.400,0.500,0.700,0.800;0.800)	Important (I)	(0.300,0.500,0.600,0.800;0.800)
High (H)	(0.500,0.600,0.750,0.850;0.900)	Very Important (VI)	(0.400,0.600,0.700,0.800;0.900)
Very high (VH)	(0.600,0.700,0.800,0.900;1.000)	Absolutely Important (AI)	(0.500,0.700,0.800,0.900;1.000)

Table 6.3: Appropriateness rating and priority weights (in linguistic terminology) against individual 3rd level indices as provided by the DMs

3rd level Indices, (C_{ijk})	Appropriateness priority rating					Priority weights				
	DM_1	DM_2	DM_3	DM_4	DM_5	DM_1	DM_2	DM_3	DM_4	DM_5
($C_{1,1,1}$)	VH	VH	VH	VH	VH	AI	AI	VI	VI	AI
($C_{1,1,2}$)	H	L	VH	H	VL	UI	AI	MI	VI	VI
($C_{1,1,3}$)	M	L	L	H	VH	UI	AI	MI	VI	VI
($C_{1,1,4}$)	VH	VH	VH	VH	VL	UI	AI	AI	VI	VI
($C_{1,1,5}$)	H	H	VH	VH	H	UI	AI	VI	VI	VI
($C_{1,2,1}$)	M	H	H	VH	M	AI	AI	UI	AI	VI
($C_{1,2,2}$)	M	M	H	H	M	AI	UI	AI	I	VI
($C_{1,3,1}$)	VH	L	L	M	VH	AI	MI	I	I	AI
($C_{1,3,2}$)	H	VH	M	M	H	AI	MI	I	I	AI
($C_{2,1,1}$)	L	M	VH	L	VL	UI	MI	AI	I	AI
($C_{2,1,2}$)	L	M	M	VH	H	I	MI	UI	AI	UI
($C_{2,1,3}$)	M	M	M	VH	H	I	I	VI	MI	UI
($C_{2,1,4}$)	VH	M	M	VH	H	I	I	VI	MI	UI
($C_{2,2,1}$)	VH	M	M	H	VH	I	MI	AI	VI	VI
($C_{2,2,2}$)	H	VH	VH	H	VL	UI	AI	MI	VI	VI
($C_{2,2,3}$)	M	M	L	VH	M	UI	AI	MI	VI	AI
($C_{2,2,4}$)	M	H	VH	VL	M	UI	AI	MI	VI	AI
($C_{2,2,5}$)	VH	H	VH	VH	H	AI	AI	AI	VI	UI
($C_{2,2,6}$)	VH	M	H	VH	H	AI	AI	VI	VI	UI
($C_{3,1,1}$)	M	M	H	L	H	AI	AI	AI	AI	UI
($C_{3,1,2}$)	L	M	M	L	H	AI	MI	VI	MI	UI
($C_{3,1,3}$)	VH	M	VH	VH	VH	AI	MI	VI	MI	UI
($C_{3,1,4}$)	H	VH	VH	VH	VH	AI	MI	VI	MI	UI
($C_{3,1,5}$)	VH	L	VH	VL	VH	AI	MI	AI	AI	UI
($C_{3,2,1}$)	VH	M	H	VH	M	UI	MI	UI	VI	UI
($C_{3,2,2}$)	VH	M	H	H	VH	I	UI	UI	VI	MI
($C_{3,2,3}$)	VH	M	VH	VL	VL	I	AI	AI	VI	MI
($C_{3,2,4}$)	M	M	VH	VH	VH	I	AI	MI	VI	MI
($C_{3,2,5}$)	M	M	M	L	H	AI	UI	MI	VI	MI
($C_{3,2,6}$)	VH	VH	VL	L	H	AI	MI	MI	AI	MI

$(C_{3,3,1})$	M	VH	VH	H	VH	UI	MI	MI	UI	MI
$(C_{3,3,2})$	H	M	VH	VH	VH	UI	MI	UI	AI	VI
$(C_{3,3,3})$	VH	VH	VH	VH	VH	I	MI	VI	MI	UI
$(C_{3,3,4})$	M	VH	M	H	H	I	AI	VI	MI	UI
$(C_{3,3,5})$	VH	M	H	VL	H	I	UI	VI	UI	UI
$(C_{3,3,6})$	M	M	M	H	VL	I	UI	VI	VI	UI
$(C_{4,1,1})$	VH	VH	H	VH	VH	UI	UI	UI	VI	AI
$(C_{4,1,2})$	M	VH	M	H	L	UI	UI	UI	VI	AI
$(C_{4,1,3})$	H	L	VH	M	H	UI	UI	AI	VI	MI
$(C_{4,2,1})$	VH	M	H	VH	H	UI	VI	VI	MI	MI
$(C_{4,2,2})$	H	M	H	L	L	AI	VI	VI	MI	VI
$(C_{4,2,3})$	VH	VH	H	VH	VH	AI	AI	VI	MI	AI
$(C_{4,2,4})$	VH	L	VH	L	L	AI	AI	AI	UI	AI

Table 6.4: Priority weights (in linguistic terminology) against individual 2nd and 1st level indices as assigned by DMs

2nd level indices (C_{ij})	Priority weights					1st level indices (C_i)	Priority weights				
	DM_1	DM_2	DM_3	DM_4	DM_5		DM_1	DM_2	DM_3	DM_4	DM_5
$(C_{1,1})$	AI	AI	VI	VI	AI	(C_1)	AI	AI	VI	VI	AI
$(C_{1,2})$	MI	AI	MI	VI	AI	(C_2)	MI	AI	MI	VI	AI
$(C_{1,3})$	AI	AI	MI	AI	UI	(C_3)	AI	AI	MI	AI	UI
$(C_{2,1})$	UI	AI	AI	UI	AI	(C_4)	UI	AI	AI	UI	AI
$(C_{2,2})$	UI	AI	UI	AI	MI						
$(C_{3,1})$	UI	AI	UI	MI	MI						
$(C_{3,2})$	UI	UI	UI	MI	UI						
$(C_{3,3})$	AI	MI	UI	UI	VI						
$(C_{4,1})$	AI	MI	I	VI	VI						
$(C_{4,2})$	UI	MI	AI	VI	AI						

Table 6.5: Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of individual 3rd level indices

3rd level indices	Priority Rating	Priority weights
($C_{1,1,1}$)	(0.600,0.700,0.800,0.900;1.000)	(0.460,0.660,0.760,0.860;0.960)
($C_{1,1,2}$)	(0.340,0.420,0.590,0.720;0.820)	(0.300,0.500,0.600,0.700;0.820)
($C_{1,1,3}$)	(0.340,0.400,0.630,0.790;0.820)	(0.300,0.500,0.600,0.700;0.820)
($C_{1,1,4}$)	(0.480,0.580,0.680,0.780;0.920)	(0.360,0.560,0.660,0.760;0.880)
($C_{1,1,5}$)	(0.540,0.640,0.770,0.870;0.940)	(0.340,0.540,0.640,0.740;0.860)
($C_{1,2,1}$)	(0.480,0.580,0.740,0.840;0.880)	(0.380,0.580,0.680,0.780;0.900)
($C_{1,2,2}$)	(0.440,0.540,0.720,0.820;0.840)	(0.340,0.540,0.640,0.760;0.860)
($C_{1,3,1}$)	(0.360,0.420,0.640,0.800;0.840)	(0.360,0.560,0.660,0.800;0.860)
($C_{1,3,2}$)	(0.480,0.580,0.740,0.840;0.880)	(0.360,0.560,0.660,0.800;0.860)
($C_{2,1,1}$)	(0.240,0.300,0.520,0.680;0.760)	(0.300,0.500,0.600,0.720;0.820)
($C_{2,1,2}$)	(0.400,0.480,0.680,0.810;0.840)	(0.200,0.400,0.500,0.620;0.740)
($C_{2,1,3}$)	(0.460,0.560,0.730,0.830;0.860)	(0.240,0.440,0.540,0.680;0.760)
($C_{2,1,4}$)	(0.500,0.600,0.750,0.850;0.900)	(0.240,0.440,0.540,0.680;0.760)
($C_{2,2,1}$)	(0.500,0.600,0.750,0.850;0.900)	(0.360,0.560,0.660,0.780;0.860)
($C_{2,2,2}$)	(0.440,0.540,0.660,0.760;0.880)	(0.300,0.500,0.600,0.700;0.820)
($C_{2,2,3}$)	(0.380,0.460,0.670,0.800;0.820)	(0.320,0.520,0.620,0.720;0.840)
($C_{2,2,4}$)	(0.380,0.480,0.630,0.730;0.820)	(0.320,0.520,0.620,0.720;0.840)
($C_{2,2,5}$)	(0.560,0.660,0.780,0.880;0.960)	(0.380,0.580,0.680,0.780;0.900)
($C_{2,2,6}$)	(0.520,0.620,0.760,0.860;0.920)	(0.360,0.560,0.660,0.760;0.880)
($C_{3,1,1}$)	(0.380,0.460,0.670,0.800;0.820)	(0.400,0.600,0.700,0.800;0.920)
($C_{3,1,2}$)	(0.300,0.360,0.610,0.770;0.780)	(0.260,0.460,0.560,0.660;0.780)
($C_{3,1,3}$)	(0.560,0.660,0.780,0.880;0.960)	(0.260,0.460,0.560,0.660;0.780)
($C_{3,1,4}$)	(0.580,0.680,0.790,0.890;0.980)	(0.260,0.460,0.560,0.660;0.780)
($C_{3,1,5}$)	(0.380,0.460,0.610,0.740;0.860)	(0.340,0.540,0.640,0.740;0.860)
($C_{3,2,1}$)	(0.500,0.600,0.7500.850;0.900)	(0.120,0.320,0.420,0.520;0.680)
($C_{3,2,2}$)	(0.520,0.620,0.760,0.860;0.920)	(0.180,0.380,0.480,0.600;0.720)
($C_{3,2,3}$)	(0.320,0.420,0.540,0.640;0.800)	(0.380,0.580,0.680,0.800;0.880)
($C_{3,2,4}$)	(0.520,0.620,0.760,0.860;0.920)	(0.320,0.520,0.620,0.740;0.820)
($C_{3,2,5}$)	(0.360,0.440,0.660,0.790;0.800)	(0.260,0.460,0.560,0.660;0.780)
($C_{3,2,6}$)	(0.360,0.440,0.600,0.730;0.840)	(0.320,0.520,0.620,0.720;0.820)
($C_{3,3,1}$)	(0.540,0.640,0.770,0.870;0.940)	(0.120,0.320,0.420,0.520;0.660)
($C_{3,3,2}$)	(0.540,0.640,0.770,0.870;0.940)	(0.220,0.420,0.520,0.620;0.760)

($C_{3,3,3}$)	(0.600,0.700,0.800,0.900;1.000)	(0.220,0.420,0.520,0.640;0.740)
($C_{3,3,4}$)	(0.480,0.580,0.740,0.840;0.880)	(0.280,0.480,0.580,0.700;0.800)
($C_{3,3,5}$)	(0.400,0.500,0.640,0.740;0.840)	(0.140,0.340,0.440,0.560;0.700)
($C_{3,3,6}$)	(0.340,0.440,0.610,0.710;0.780)	(0.220,0.420,0.520,0.640;0.760)
($C_{4,1,1}$)	(0.580,0.680,0.790,0.890;0.980)	(0.180,0.380,0.480,0.580;0.740)
($C_{4,1,2}$)	(0.400,0.480,0.680,0.810;0.840)	(0.180,0.380,0.480,0.580;0.740)
($C_{4,1,3}$)	(0.420,0.500,0.690,0.820;0.860)	(0.220,0.420,0.520,0.620;0.760)
($C_{4,2,1}$)	(0.520,0.620,0.760,0.860;0.920)	(0.240,0.440,0.540,0.640;0.760)
($C_{4,2,2}$)	(0.320,0.380,0.620,0.780;0.800)	(0.380,0.580,0.680,0.780;0.880)
($C_{4,2,3}$)	(0.580,0.680,0.790,0.890;0.980)	(0.420,0.620,0.720,0.820;0.920)
($C_{4,2,4}$)	(0.300,0.340,0.590,0.780;0.820)	(0.400,0.600,0.700,0.800;0.920)

Table 6.6: Computed fuzzy appropriateness rating and aggregated fuzzy priority weights of individual 2nd level indices

2nd level indices	Priority Rating	Priority weights
($C_{1,1}$)	(0.222,0.473,0.827,1.743;0.600)	(0.460,0.660,0.760,0.860;0.900)
($C_{1,2}$)	(0.241,0.476,0.861,1.776;0.600)	(0.360,0.560,0.660,0.760;0.700)
($C_{1,3}$)	(0.189,0.424,0.813,1.778;0.700)	(0.340,0.540,0.640,0.740;0.600)
($C_{2,1}$)	(0.142,0.391,0.815,2.110;0.600)	(0.300,0.500,0.600,0.700;0.600)
($C_{2,2}$)	(0.219,0.475,0.842,1.783;0.600)	(0.240,0.440,0.540,0.640;0.600)
($C_{3,1}$)	(0.186,0.433,0.825,1.884;0.600)	(0.180,0.380,0.480,0.580;0.600)
($C_{3,2}$)	(0.161,0.422,0.813,1.996;0.600)	(0.040,0.240,0.340,0.440;0.600)
($C_{3,3}$)	(0.162,0.467,0.903,2.521;0.600)	(0.220,0.420,0.520,0.620;0.600)
($C_{4,1}$)	(0.151,0.440,0.902,2.577;0.600)	(0.360,0.560,0.660,0.780;0.700)
($C_{4,2}$)	(0.201,0.424,0.810,1.745;0.600)	(0.320,0.520,0.620,0.720;0.600)

Table 6.7: Computed fuzzy appropriateness rating and aggregated fuzzy priority weights of individual 1st level indices

1 st level indices	Priority Rating	Priority weights
(C1)	(0.107,0.392,0.975,3.590;0.600)	(0.460,0.660,0.760,0.860;0.900)
(C2)	(0.071,0.355,1.004,4.848;0.600)	(0.360,0.560,0.660,0.760;0.700)
(C3)	(0.046,0.345,1.098,8.031;0.600)	(0.340,0.540,0.640,0.740;0.600)
(C4)	(0.079,0.365,1.016,4.803;0.600)	(0.300,0.500,0.600,0.700;0.600)

Table 6.8: Computed utility value for individual 3rd level evaluation indices and corresponding ranking order $(\alpha = 0, 0.5, 1)$

3rd level indices		Ranking order		Ranking order		Ranking order
	$\alpha = 0$		$\alpha = 0.5$		$\alpha = 1$	
($C_{1,1,1}$)	0.3239	36	0.1787	37	0.0335	43
($C_{1,1,2}$)	0.3385	34	0.2549	31	0.1712	26
($C_{1,1,3}$)	0.3611	32	0.2822	28	0.2032	23
($C_{1,1,4}$)	0.4059	26	0.2731	29	0.1403	33
($C_{1,1,5}$)	0.5575	18	0.3857	17	0.2139	20
($C_{1,2,1}$)	0.3571	33	0.2496	34	0.1420	32
($C_{1,2,2}$)	0.4163	25	0.2936	25	0.1709	27
($C_{1,3,1}$)	0.2403	38	0.1685	38	0.0967	39
($C_{1,3,2}$)	0.3888	28	0.2526	32	0.1165	36
($C_{2,1,1}$)	0.1812	41	0.1532	40	0.1252	35
($C_{2,1,2}$)	0.6455	14	0.4928	14	0.3400	12
($C_{2,1,3}$)	0.7102	12	0.5335	12	0.3568	9
($C_{2,1,4}$)	0.7136	11	0.5396	11	0.3138	15
($C_{2,2,1}$)	0.4295	24	0.2900	27	0.1506	31
($C_{2,2,2}$)	0.5490	19	0.3770	18	0.2049	22
($C_{2,2,3}$)	0.3874	29	0.2905	26	0.1936	24
($C_{2,2,4}$)	0.3658	31	0.2645	30	0.1632	28
($C_{2,2,5}$)	0.4809	22	0.3207	23	0.1605	29
($C_{2,2,6}$)	0.4835	21	0.3317	22	0.1800	25
($C_{3,1,1}$)	0.2253	39	0.1580	39	0.0907	40
($C_{3,1,2}$)	0.3788	30	0.3087	24	0.2387	19

($C_{3,1,3}$)	0.7849	9	0.5600	9	0.3356	13
($C_{3,1,4}$)	0.8150	8	0.5787	8	0.3424	11
($C_{3,1,5}$)	0.3153	37	0.2258	36	0.1363	34
($C_{3,2,1}$)	1.0216	2	0.7650	2	0.5084	2
($C_{3,2,2}$)	0.9028	5	0.6617	5	0.4207	4
($C_{3,2,3}$)	0.1422	42	0.0899	43	0.0376	42
($C_{3,2,4}$)	0.5636	17	0.3884	16	0.2132	21
($C_{3,2,5}$)	0.4790	23	0.3711	20	0.2633	17
($C_{3,2,6}$)	0.3298	35	0.2406	35	0.1514	30
($C_{3,3,1}$)	1.0954	1	0.8112	1	0.5269	1
($C_{3,3,2}$)	0.8528	6	0.6193	6	0.3857	6
($C_{3,3,3}$)	0.9354	4	0.6647	4	0.3941	5
($C_{3,3,4}$)	0.6055	16	0.4356	15	0.2657	16
($C_{3,3,5}$)	0.8194	7	0.5954	7	0.3713	8
($C_{3,3,6}$)	0.4841	20	0.3690	21	0.2538	18
($C_{4,1,1}$)	1.0187	3	0.7387	3	0.4588	3
($C_{4,1,2}$)	0.7000	13	0.5137	13	0.3792	7
($C_{4,1,3}$)	0.6494	14	0.4924	15	0.3355	14
($C_{4,2,1}$)	0.7732	10	0.5610	10	0.3501	10
($C_{4,2,2}$)	0.1909	40	0.1440	41	0.0971	38
($C_{4,2,3}$)	0.4029	27	0.2510	33	0.0991	37
($C_{4,2,4}$)	0.1196	43	0.0942	43	0.0687	41

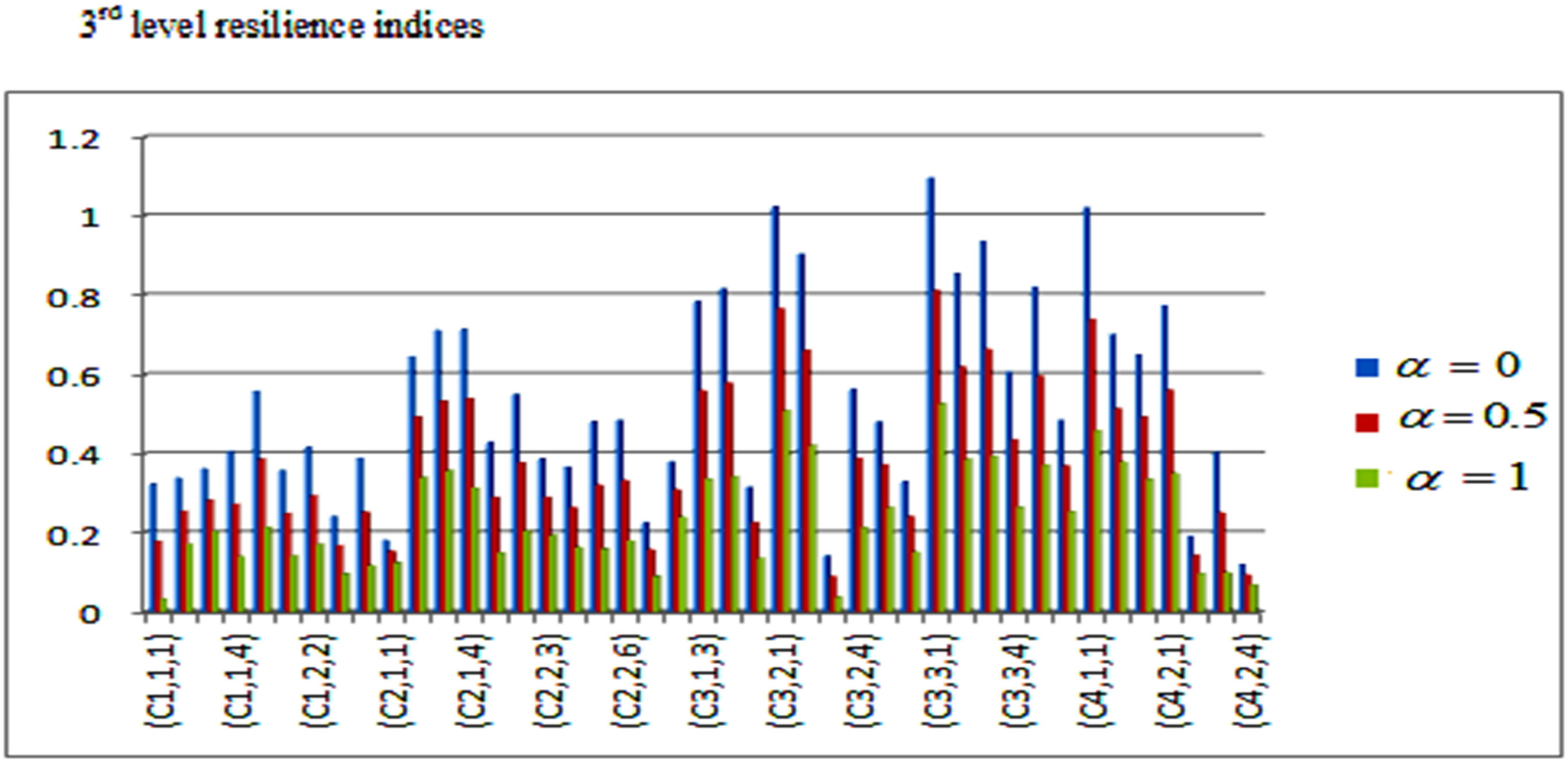

Fig 6.2: Bar chart analysis revealing raking order of individual 3rd level resilience indices in accordance with total utility value for $(\alpha = 0, 0.5, 1)$

CHAPTER 7

RESILIENT SUPPLIER SELECTION

7.1 Coverage

Supply chains have become increasingly vulnerable to catastrophic events/disruptions that may be natural or man-made. Hurricanes, Tsunamis and floods are natural disasters, whereas, manmade disasters may be strikes, terrorist attacks, etc. Failure at any point in the supply chain network has the potential to cause the entire network to fail. Supply chains must, therefore, be properly designed to survive well in the disruption scenario. The capability of successful survival (of the firm's supply chain) against those adverse events/happenings is termed as resilience; and, the supply chain designed under resilience consideration is called a resilient supply chain. Effective supplier selection is considered as a key strategic consideration in supply chain management. It is felt that apart from considering traditional suppliers selection criteria, suppliers' resiliency strategy must be incorporated while selecting a potential supplier which can provide best support to the firm even in the disaster/disruption scenario. To this end, present work focuses aspects of evaluation and selection of resilience supplier by considering general as well as resiliency strategy, simultaneously. In this work, subjectivity associated with ill-defined (vague) evaluation information has been tackled through logical exploration of fuzzy numbers set theory. Application of VIKOR embedded with fuzzy mathematics has been utilized here. Sensitivity analysis has been performed to reflect the effect of decision-makers' risk-bearing attitude in selecting the potential supplier in a resilient supply chain. A case empirical example has also been presented.

7.2 Problem Definition

In the present work, an efficient decision support system has been adapted to facilitate evaluation and selection of resilient suppliers in fuzzy context. Apart from general strategies of suppliers (viz. product quality C_1, product reliability C_2, product functionality C_3, extent of customer satisfaction C_4 and product price C_5); resiliency strategies like investment in capacity buffers R_1, responsiveness R_2, capacity for holding strategic inventory stocks for crises R_3 have also been considered. Since most of the evaluation criterions are subjective in nature; which invites some kind of ambiguity and vagueness; the said decision support system has to rely on decision-makers' subjective evaluation information expressed in linguistic terminologies. Linguistic expert data has been transformed into appropriate trapezoidal fuzzy numbers. Next, an improved fuzzy-VIKOR method has been adapted towards evaluating the ranking order of candidate suppliers based on general strategy only. In this computation, the ranking order has been derived in view of the 'VIKOR INDEX, Q' (adapted from the theory of VIKOR method) of individual supplier alternatives. Moreover, based on the resiliency strategy, performance ranking order of alternative suppliers has been obtained in view of their 'overall suitability index'. The final 'supplier selection score' has thus been obtained by utilizing supplier selection indices based on aforesaid two strategies i.e. general as well as resiliency strategies; thus, providing the ultimate choice to the best supplier. In computing 'supplier selection score', decision-makers' risk bearing attitude has been incorporated. Sensitivity analysis has been carried out to show how the variation of decision-making attitude influences the choice of the potential supplier. A case empirical illustration has also been provided here.

7.3 Methodology

The work explores a decision support framework combining VIKOR method which has been extended (improved) to operate in fuzzy environment. The following sections deal with the traditional VIKOR based Multi-Criteria Decision Making (MCDM) approach and the improved VIKOR method (Fuzzy-VIKOR) in the said supplier selection problem. To start with fuzzy-VIKOR, the basic understanding on fuzzy preliminaries (fuzzy sets and fuzzy numbers, notations of fuzzy numbers, fuzzy operational rules and defuzzification formulae of fuzzy numbers) are indeed necessary. These could be found in [Carlsson and Fuller, 2000; Chen, 2000; Chen and Hwang, 1992; Li, 2003; Zimmermann, 1991; Bagis, 2003; Carlsson and Fuller, 2000; Cerrada, 2005; Hu, 2006; Medaglia, et al., 2002; Simon, 2005; Wang and Chuu, 2004; Yang and Bose, 2006; Zimmermann and Zysno, 1985].

7.3.1 VIKOR Method

(Opricovic, 1998), (Opricovic and Tzeng, 2002) developed VIKOR, the Serbian name: *VIse Kriterijumska Optimizacija I Kompromisno Resenje*, means multi-criteria optimization and compromise solution (Chu et al., 2007). The VIKOR method was developed for multi-criteria optimization of complex systems (Opricovic and Tzeng, 2004). This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision-makers to reach a final decision. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions (Opricovic and Tzeng, 2007). It introduces the multi-criteria ranking index based on the particular measure of 'closeness' to the 'ideal' solution (Opricovic, 1998).

According to (Opricovic and Tzeng, 2004), the multi-criteria measure for compromise ranking is developed from the PL_p metric used as an aggregating function in a compromise programming method (Yu, 1973). The various J alternatives are denoted as $a_1, a_2, ..., a_J$. For alternative a_j, the rating of the i^{th} aspect is denoted by f_{ij}, i.e. f_{ij} is the value of i^{th} criterion function for the alternative a_j; n is the number of criteria. Development of the VIKOR method started with the following form of L_p -metric:

$$L_{p,j} = \left\{ \sum_{i=1}^{n} \left[w_i \left(f_i^* - f_{ij}\right) \Big/ \left(f_i^* - f_i^-\right) \right]^p \right\}^{\frac{1}{p}}, 1 \leq p \leq \infty;\ j = 1,2,..., J. \quad (7.1)$$

Within the VIKOR method $L_{1,j}$ (as S_j) and $L_{\infty,j}$ (as R_j) are used to formulate the ranking measure. The $L_{1,j}$ is interpreted as 'concordance' and can provide decision makers with information about the maximum group 'utility' or 'majority'. Similarly, $L_{\infty,j}$ is interpreted as 'discordance' and provides decision-makers with information about the minimum individual regret of the 'opponent' (Sanayei et al., 2010).

7.3.2 Fuzzy-VIKOR

A systematic approach to extend the VIKOR as proposed by (Sanayei et al., 2009; 2010) has been explored here to solve the resilient supplier selection problem under fuzzy environment. In this module the importance weights of various criteria and the ratings of criteria have also been considered as linguistic variables (assuming all criterions are subjective/ qualitative in nature). Because linguistic assessments merely approximate the subjective judgment of decision-makers, it has been felt that linear trapezoidal membership functions could be adequate for capturing the vagueness of these linguistic assessments.

In fact, supplier selection in supply chain system is a group multiple criteria decision making (GMCDM) problem, which may be described by means of the following, sets (Chen et al., 2006):

i. a set of *K* decision makers called $E = \{D_1, D_2, D_3, ..., D_K\}$;

ii. a set of *m* possible suppliers called $A = \{A_1, A_2, A_3, ..., A_m\}$;

iii. a set of *n* criteria, $C = \{C_1, C_2, C_3, ..., C_n\}$, with which supplier performances are measured;

iv. a set of performance ratings of $A_i (i = 1, 2.3, ..., m)$ with respect to criteria $C_j (j = 1, 2, 3, ..., n)$, called $X = \{x_{ij},\ i = 1,2,..., m;\ j = 1,2,..., n\}$

The main steps of the algorithms are:

Step 1: Identify the objectives of the decision making process and define the problem scope

Decision making is the process of defining the decision goals, gathering relevant information and selecting the optimal alternative (Hess and Siciliano, 1996). Thus, the first step is defining the decision goal that here is to evaluate and select a favorable resilient supplier/s.

Step 2: Arrange the decision making group and define and describe a finite set of relevant attributes

In supplier evaluation and selection process a number of decision-makers (experts) from different functional areas within the company are involved. So, with considering the problem scope defined in previous section and its entire dimension, a group of decision-makers must be formed.

Supplier selection first requires identification of decision attributes (criteria) then evaluation scales/metrics are determined in order to measure appositeness of supplier. These criteria must be defined according to the corporate strategies, company's competitive situation, the level of buyer–supplier integration (Ghodsypour and O'Brien, 1998) and type of product which needs to be outsourced.

Step 3: Identify the appropriate linguistic variables

In this step, the appropriate linguistic variables for the importance weight of criteria, and the fuzzy rating for alternatives with regard to each criterion are defined; these linguistic variables can be expressed in positive trapezoidal fuzzy numbers, as in Tables 7.2-7.3. It is suggested that the decision-makers should use the linguistic variables shown in Tables 7.2-7.3 to evaluate the importance (weight) of the criteria and the ratings of alternatives with respect to qualitative criteria.

Step 4: Pull the decision makers' opinions to get the aggregated fuzzy weight of criteria, and aggregated fuzzy rating of alternatives and construct a fuzzy decision matrix

Let the fuzzy rating and importance weight of the k^{th} decision maker be $\tilde{x}_{ijk} = (x_{ijk1,} x_{ijk2,} x_{ijk3,} x_{ijk4})$ and $\tilde{w}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3}, w_{jk4}); i = 1,2,..., m; j = 1,2,..., n,$ respectively. Hence, the aggregated fuzzy ratings of $(\tilde{x}_{ij})$ alternatives with respect to each criterion can be calculated as:

$$\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}), \tag{7.2}$$

Here,

$$x_{ij1} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk1}, x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2}, x_{ij3} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk3}, x_{ij4} = \frac{1}{K}.\sum_{k=1}^{K} x_{ijk4}$$

The aggregated fuzzy weights $(\tilde{w}_j)$ of each criterion can be calculated as:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \tag{7.3}$$

Here,

$$w_{j1} = \frac{1}{K}\sum_{k=1}^{K} w_{jk1}, w_{j2} = \frac{1}{K}\sum_{k-1}^{K} w_{jk2}, w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3}, w_{j4} = \frac{1}{K}\sum_{k=1}^{K} w_{jk4}$$

A supplier selection problem can be concisely expressed in matrix format as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \vdots & \tilde{x}_{mn} \end{bmatrix}, \ \tilde{W} = [\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n],$$

where $\tilde{x}_{ij}$ the rating of alternative A_i with respect to C_j, $\tilde{w}_j$ the importance weight of the j^{th} criterion holds, $\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$ and

$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}); \ i = 1,2,..., m; \ j = 1,2,..., n$ are linguistic variables can be approximated by positive trapezoidal fuzzy numbers.

Step 5: Defuzzifying the fuzzy decision matrix and fuzzy weight of each criterion into crisp values

Also the crisp value of the fuzzy number $\widetilde{A} = (a_1, a_2, a_3, a_4)$ based on Center of Area (COA) method can be expressed by following relation (Sanayei et al., 2010):

$$defuzz(\widehat{A}) = \frac{\int x \cdot \mu(x)dx}{\int \mu(x)dx}$$
$$= \frac{\int_{a_1}^{a_2} \left(\frac{x - a_1}{a_2 - a_1} \right) \cdot xdx + \int_{a_2}^{a_3} xdx + \int_{a_3}^{a_4} \left(\frac{a_4 - x}{a_4 - a_3} \right) \cdot xdx}{\int_{a_1}^{a_2} \left(\frac{x - a_1}{a_2 - a_1} \right) dx + \int_{a_2}^{a_3} dx + \int_{a_3}^{a_4} \left(\frac{a_4 - x}{a_4 - a_3} \right) dx}$$
$$= \frac{-a_1 a_2 + a_3 a_4 + \frac{1}{3}(a_4 - a_3)^2 - \frac{1}{3}(a_2 - a_1)^2}{-a_1 - a_2 + a_3 + a_4}. \tag{7.4}$$

Step 6: Determine the best f_j^* and the worst f_j^- values of all criterion ratings, $j = 1, 2, 3, ..., n$

$$f_j^* = \max_i x_{ij}; \tag{7.5}$$

$$f_j^- = \min_i x_{ij}. \tag{7.6}$$

Step 7: Compute the values S_i and R_i by the relations

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) \Big/ \left(f_j^* - f_j^-\right) \tag{7.7}$$

$$R_i = \max_j w_j \left(f_j^* - f_{ij}\right) \Big/ \left(f_j^* - f_j^-\right) \tag{7.8}$$

Step 8: Compute the values Q_i by the relations

$$Q_i = \nu \left(S_i - S^*\right) \Big/ \left(S^- - S^*\right) + (1 - \nu) \left(R_i - R^*\right) \Big/ \left(R^- - R^*\right) \tag{7.9}$$

Here

$S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$ and ν is introduced as a weight for the strategy of maximum group utility, whereas $1 - \nu$ is the weight of the individual regret.

Step 9: Rank the alternatives, sorting by the values S, R and Q in ascending order

Step 10: Propose as a compromise solution the alternative $(A^{(1)})$ which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied.

C1. Acceptable advantage:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ, \tag{7.10}$$

where $A^{(2)}$ is the alternative with second position in the ranking list by $Q; DQ = 1/(J-1)$.

C2. Acceptable stability in decision making:

The alternative $A^{(1)}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" $v \approx 0.5$, or "with veto" ($v < 0.5$). Here, v is the weight of decision making strategy of maximum group utility.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied,

  OR
- Alternatives $A^{(1)}, A^{(2)}, \ldots A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

7.4 Proposed Decision Support Framework

It has been assumed that a company wishes to develop a proactive resiliency strategy to rank potential suppliers as its commitment to the global marketplace. A finite number of candidate suppliers have been identified for this analysis. From different functional areas, five decision-makers (experts) participated towards evaluating the suppliers. The criteria set for supplier evaluation has been based upon general strategy as well as suppliers' resiliency strategy. Under general strategy the following criterions have been considered as the suppliers' evaluation indices: Product quality, (C_1); Reliability of the product, (C_2); Functionality of the product, (C_3); Extent of customer satisfaction, (C_4); Product price, (C_5). Apart from general strategy, the following have been considered under resiliency strategy viz. Investment in capacity buffers, (R_1) Responsiveness, (R_2) Capacity for holding strategic inventory stocks for crises, (R_3). Thus, the combined selection criterions for resilient supplier selection has been depicted in Table 7.1; adapted from the work by (Haldar et al., 2014). Table 7.2 represents the set of linguistic variables and corresponding fuzzy representative scale [0, 1] for assigning priority weights against individual supplier selection criterions (under general as well as resiliency strategy both). The set of linguistic variables and corresponding fuzzy representative scale [0, 10] for assigning (appropriateness) ratings against individual supplier selection criterions (under general as well as resiliency strategy both) have been shown in Table 7.3. The transformation of linguistic variable into fuzzy number is a logical approach to avoid inherent uncertainty, imprecision and incompleteness that arise due to subjective human (expert) judgment. Here each fuzzy number is represented by the trapezoidal membership function (generalized trapezoidal fuzzy numbers). The entire decision making module has been made consisting of the following three steps.

Step 1: Determination of 'VIKOR INDEX, Q_i' of supplier alternatives under general strategy.

Step 2: Determination of 'overall suitability index' of supplier alternatives under resiliency strategy.

Step 3: Determination of final 'supplier selection score' (SSS) followed by ranking of the supplier alternatives. In this step, suppliers are ranked individually on the basis of general strategy and resiliency strategy. Finally, these two choices are combined for final ranking of the suppliers.

7.5 Case Empirical Research

The procedural steps of the said decision support module could be well understood through the following case empirical research. Table 7.2 exhibits a 7-member linguistic terms set **[Very Low (VL); Low (L); Medium Low (ML); Medium (M); Medium High (MH); High (H) and Very High (VH)]** by exploring which, decision-makers (DMs) have been instructed to assign priority importance (weight) against individual supplier selection criterions. Similarly, DMs have been asked to use another 7-member linguistic terms set (Table 7.3) **[Very Poor (VP); Poor (P); Medium Poor (MP); Fair (F); Medium Good (MG); Good (G); Very Good (VG)]** to provide ratings of different evaluation criterions for each alternative suppliers.

Step 1: In this step, the 'VIKOR INDEX, Q_i' of individual supplier alternatives under general strategy have been computed by exploring the technique called Fuzzy-VIKOR. The importance weights against individual evaluation indices (C_1, C_2, C_3, C_4 and C_5) as assigned by DMs have been furnished in Table 7.4, and Corresponding aggregated fuzzy weights (AFW) of each criterion have also been computed based on Eq. (7.3). Tables 7.5.1-7.5.5 represent appropriateness ratings (expressed in linguistic terminology) against individual evaluation indices as assigned by DMs (for alternative $\mathbf{S_1}$, $\mathbf{S_2}$, $\mathbf{S_3}$, $\mathbf{S_4}$, $\mathbf{S_5}$, respectively); and corresponding aggregated fuzzy ratings (AFR) (computed using Eq. 7.2). The decision-matrix has thus been obtained and shown in Table 7.6. The normalized decision matrix has been formed using the formulae as provided in [Li, 2003; 2007] and furnished in Table 7.7.

From Table 7.7, the crisp values for the decision matrix and weight of each criterion (under general strategy) have been computed (using Eq. 7.4) as shown in Table 7.8. The best and the worst values of all criterion ratings have been determined as follows:

$$f_1^* = 0.898,\ f_2^* = 0.898,\ f_3^* = 0.922,\ f_4^* = 0.945,\ f_5^* = 0.536$$

$$f_1^- = 0.510,\ f_2^- = 0.670,\ f_3^- = 0.610,\ f_4^- = 0.700,\ f_5^- = 0.788$$

The values of **S**, **R** and **Q** have been computed for all suppliers and shown in Table 7.9. The ranking order of candidate suppliers by **S**, **R** and **Q** in decreasing order has been shown in Table 7.10. Based on Q, the ranking order of alternative suppliers (under general strategy) appears as $\mathbf{S_2 > S_4 > S_5 > S_1 > S_3}$.

Step 2: In this step, the 'overall suitability index' of individual supplier alternatives under resiliency strategy has been determined. A disrupted supply chain network requires dynamic evaluation of strategic planning. Three strategic planning criterions have been considered in developing resiliency in the supply chain system viz. R_1, R_2 and R_3 as shown in Table 7.1. The priority weight (expressed in linguistic terms) of each of the three resiliency criteria given by the individual DMs have been tabulated in Table 7.11. Table 7.11 also represents the Aggregated Fuzzy Weight (AFW_{Ri}) of the resiliency criteria (R_1, R_2 and R_3) computed using Eq. (7.3). Now, each DM rates each alternative with respect to each criterion and the data have been tabulated (Tables 7.12-7.16). Due to the fact that the expert judgments partially depend on personal preference, the DMs' recommendations have been expressed through linguistic terminologies which have further been transformed into appropriate generalized trapezoidal fuzzy numbers. Applying Eqs. (7.2), the Weighted Aggregated Fuzzy Rating ($WAFR_{DMi}$) (for individual DMs) against each of the alternatives have been determined and shown in Table 7.12, 7.13, 7.14, 7.15 and 7.16, respectively. Weighted Aggregated Fuzzy Ratings (WAFRs) of alternative suppliers by each of the five decision-makers for the three resiliency criteria have been tabulated in Table 7.17. Now, the Overall Suitability Index (OSI_{Ri}) of each of the alternatives has been determined and shown in Table 7.17.

Using the equation given by (Sanayei et al., 2010), $E = \dfrac{-a_1 a_2 + a_3 a_4 + \frac{1}{3}(a_4 - a_3)^2 - \frac{1}{3}(a_2 - a_1)^2}{-a_1 - a_2 + a_3 + a_4}$, the Overall Suitability Index has been determined from the defuzzified value concept of the trapezoidal fuzzy number (a_1, a_2, a_3, a_4).

Now values of VIKOR INDEX (Q_i) of the alternatives for general strategy and Overall Suitability Index (OSI_{Ri}) for resiliency strategy have been normalized (Q_{Ni}, and OSI_{NRi}, respectively) to get the ranking order of supplier alternatives based on aforementioned two strategies (Table 7.18).

Sensitivity Analysis

Sensitivity analysis makes the supplier selection process more robust. A trade-off between general selection criteria and resiliency criteria have been done using 'Sensitivity Analysis', where, a 'Supplier Selection Score' (SSS) has been measured for each of the candidate suppliers. Here, the SSS has been computed using the method proposed by (Ray et al., 2010). Fig. 7.1 shows optimal region for both the suppliers.

$$(SSS)_i = \left[\alpha \times Q_{N_i} + (1-\alpha) OSI_{NR_i}\right] \tag{11}$$

In this computation, the Q_{Ni} values are the normalized Q_i (obtained from fuzzy VIKOR analysis considering general strategy) and the OSI_{NRi} values are the normalized Overall Suitability Index for each supplier alternative and they are integrated into the supplier selection process to determine the supplier selection score. Here, the choice of α is an important issue. The sensitivity plot has been exhibited in Fig. 7.1. For any value of $0 \le \alpha \le 1$, S_2 is the best option. If we consider alternative suppliers except S_2, when $0 \le \alpha < 0.2$, S_5 is the best; when $0.2 < \alpha \le 1$, S_4 is the best.

Application potential of aforesaid fuzzy-VIKOR has been compared to that of Fuzzy-TOPSIS [Chen and Hwang, 1992; Hwang and Yoon, 1981; Lai and Hwang, 1994; Li, 2003; Li, 2007; Haldar et al., 2014] on the same supplier selection problem. Results have been depicted in (Table 7.19, Fig. 7.2). By comparing results of fuzzy-TOPSIS and Fuzzy-VIKOR, the best alternative is S_2. It has been observed that aforesaid two approaches providing compatible results. However, slight difference that has been noticed (on ranking order of alternative suppliers based on general strategy only) is due the working principle of TOPSIS in contrast to VIKOR. TOPSIS is based on aggregating function representing ‘‘closeness to ideal”. In TOPSIS the chosen alternative should have the ‘‘shortest distance” from the ideal solution and the ‘‘farthest distance” from the ‘‘negative-ideal”. The TOPSIS method introduces two reference points, but it does not consider the relative importance of the distances from these points (Chu et al., 2007).

7.6 Managerial Implication

Supply chain network is expected to deliver the right products (or services) on right time, with the required specifications, at the right place and to the right customer. Nowadays, supply chains are facing numerous business challenges due to market globalization; and as a consequence, supply chains are becoming much more complicated due to adaptation of modern business philosophies like lean, agile as well as leagile in order to survive successfully in the highly competitive and turbulent marketplace. The implementation of aforesaid philosophies or practices in turn brings enhanced level of risks, since SCs have become more vulnerable to disturbances (Christopher and Towill, 2000; Norrman et al., 2004; Tang, 2006). Once an SC is affected by a disturbance, its performance is jeopardized, e.g., short-term financial performance is reduced, losing competitiveness (Ji and Zhu, 2008). In order to survive, organizations and their SCs must be resilient; they must develop the ability to react to an unforeseen disturbance and to return quickly to their original stable state or move to a new, more advantageous one after suffering the said disturbances (Carvalho and Cruz Machado, 2007; Ji and Zhu, 2008; Peck, 2005). To help organizations become more resilient and, eventually, less vulnerable to disturbances, adequate design strategies reflecting contingency and mitigation policies must be defined (Machado et al., 2009). It is widely known that the overall performance of a supply chain is influenced by effective supplier selection. Therefore, to avail competitive advantage not only in stability but also to survive against unwanted disruptions; resilient supplier selection is of immense importance. To this end, forgoing work attempts to focus on a decision making procedural hierarchy towards effective supplier selection in a resilient supply chain. The work exhibits application potential of VIKOR method integrated with fuzzy set theory to select potential supplier based on general strategy as well as resiliency strategy. The final supplier selection score (obtained by considering general strategy) and that of obtained by analyzing resiliency strategy have been combined to get a final compromise solution. The decision support framework thus reported here also considers decision-makers’ risk bearing attitude. The study bears significant impact to the industry managers who are trying to adapt resiliency strategy in their supply chain followed by potential supplier selection in the context of resilient supply chain.

7.7 Concluding Remarks

The contribution of the present work has been summarized below. The work has attempted to develop of an efficient decision support framework towards resilient supplier selection by considering general as well as resiliency strategy both. Fuzzy set theory has been explored in order to tackle ambiguity and vagueness associated with decision-makers' linguistic evaluation information (expert judgment). Application feasibility of Fuzzy-VIKOR has been tested and compared with Fuzzy-TOPSIS for supplier selection under general strategy. Supplier selection scores obtained by considering general strategy and resiliency strategy, respectively, have been aggregated to compute a unique supplier selection index (supplier suitability index), and finally to determine the most favorable supplier alternative. Decision making attitude (risk bearing attitude) of decision-makers has been considered in evaluating the final ranking score. Sensitivity analysis reflects how variation of decision making attitude influences selection of supplier alternatives.

Table 7.1: Resilient supplier selection criterions

Category	Evaluation index (C_i)	Definition
General strategy	Product quality, (C_1)	It is defined as a group of features and characteristics of a saleable good which determine its desirability and can be controlled by a manufacturer to meet certain basic requirements.
	Reliability of the product, (C_2)	It is defined as an ability of product to consistently perform its intended or required function in limited period of time under prescribed operating condition.
	Functionality of the product, (C_3)	It refers to the purpose for that product is designed to fulfill customer expectation.
	Extent of customer satisfaction, (C_4)	It measures that how well the expectations of a customer concerning a product or service provided by your company have been met.
	Product price, (C_5)	It refers to the sum of all costs associated with the production of a specific quantity of a good or service.
Resiliency strategy	Investment in capacity buffers, (R_1)	It refers to ability of individual firm to investment the money for reserve the excess product as a safeguard against unforeseen shortages or demands.
	Responsiveness, (R_2)	This is the willingness to respond to customer needs with the help of several medium i.e. answering their phone or email requests quickly, by acknowledging them quickly.
	Capacity for holding strategic inventory stocks for crises, (R_3)	It is defined as a capacity of firm to holding a large stock of essential materials and goods to withstand a long period of scarcity caused by a natural disaster, war or strike action.

[Source: Haldar et al., 2014]

Table 7.2: Linguistic variables and corresponding fuzzy representative scale [0, 1] for assigning priority weights

Linguistic terms (for priority weights)	Generalized trapezoidal fuzzy numbers
Very Low (VL)	(0, 0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Medium High (MH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very High (VH)	(0.8, 0.9, 1, 1)

Table 7.3: Linguistic variables and corresponding fuzzy representative scale [0, 10] for assigning (appropriateness) ratings

Linguistic terms (for ratings)	Generalized trapezoidal fuzzy numbers
Very Poor (VP)	(0, 0, 0, 1)
Poor (P)	(0, 1, 2, 3)
Medium Poor (MP)	(2, 3, 4, 5)
Fair (F)	(4, 5, 5, 6)
Medium Good (MG)	(5, 6, 7, 8)
Good (G)	(7, 8, 9, 10)
Very Good (VG)	(9, 10, 10, 10)

Table 7.4: Importance weights against individual evaluation indices as assigned by DMs and corresponding aggregated fuzzy weights (AFW) of each criterion

Evaluation indices	Importance weight expressed in linguistic terms					AFW
	DM1	DM2	DM3	DM4	DM5	
C_1	H	H	M	H	H	(0.640,0.740,0.740,0.840)
C_2	VH	VH	VH	H	H	(0.760,0.860,0.920,0.960)
C_3	H	H	MH	H	MH	(0.620,0.720,0.760,0.860)
C_4	M	VH	H	H	H	(0.660,0.760,0.780,0.860)
C_5	VH	H	VH	H	H	(0.740,0.840,0.880,0.940)

Table 7.5.1: Appropriateness rating against individual evaluation indices as assigned by DMs (for alternative $\mathbf{S_1}$) and corresponding aggregated fuzzy ratings (AFR)

Evaluation indices	Appropriateness rating against individual 2^{nd} level evaluation indices					AFR
	DM1	DM2	DM3	DM4	DM5	
C_1	MG	F	G	MG	VG	(6.000,7.000,7.600,8.400)
C_2	F	G	MG	F	G	(5.400,6.400,7.000,8.000)
C_3	F	G	G	G	F	(5.800,6.800,7.400,8.400)
C_4	F	G	G	G	G	(6.400,7.400,8.200,9.200)
C_5	G	MG	F	VG	MG	(6.000,7.000,7.600,8.400)

Table 7.5.2: Appropriateness rating against individual evaluation indices as assigned by DMs (for alternative $\mathbf{S_2}$) and corresponding aggregated fuzzy ratings (AFR)

Evaluation indices	Appropriateness rating against individual 2^{nd} level evaluation indices					AFR
	DM1	DM2	DM3	DM4	DM5	
C_1	VG	VG	G	G	G	(7.800,8.800,9.400,10.00)
C_2	MG	VG	G	F	G	(6.400,7.400,8.000,8.800)
C_3	G	VG	MG	VG	VG	(7.800,8.800,9.200,9.600)
C_4	MG	G	MG	G	VG	(6.600,7.600,8.400,9.200)
C_5	F	VG	F	MP	VG	(5.600,6.600,6.800,7.400)

Table 7.5.3: Appropriateness rating against individual evaluation indices as assigned by DMs (for alternative **S_3**) and corresponding aggregated fuzzy ratings (AFR)

Evaluation indices	Appropriateness rating against individual 2nd level evaluation indices					AFR
	DM1	DM2	DM3	DM4	DM5	
C_1	G	MG	MG	MG	G	(5.800,6.800,7.800,8.800)
C_2	VG	MG	MG	MG	MG	(5.800,6.800,7.600,8.400)
C_3	G	MP	MG	MP	G	(4.600,5.600,6.600,7.600)
C_4	VG	G	MG	VG	VG	(7.800,8.800,9.200,9.600)
C_5	F	G	G	MP	MP	(4.400,5.400,6.200,7.200)

Table 7.5.4: Appropriateness rating against individual evaluation indices as assigned by DMs (for alternative **S_4**) and corresponding aggregated fuzzy ratings (AFR)

Evaluation indices	Appropriateness rating against individual 2nd level evaluation indices					AFR
	DM1	DM2	DM3	DM4	DM5	
C_1	G	MP	F	F	MP	(3.800,4.800,5.400,6.400)
C_2	G	G	VG	G	VG	(7.800,8.800,9.400,10.00)
C_3	VG	VG	VG	G	G	(8.200,9.200,9.600,10.00)
C_4	VG	G	VG	VG	VG	(8.600,9.600,9.800,10.00)
C_5	VG	MG	G	G	G	(7.000,8.000,8.800,9.600)

Table 7.5.5: Appropriateness rating against individual evaluation indices as assigned by DMs (for alternative **S_5**) and corresponding aggregated fuzzy ratings (AFR)

Evaluation indices	Appropriateness rating against individual 2nd level evaluation indices					AFR
	DM1	DM2	DM3	DM4	DM5	
C_1	G	G	VG	VG	G	(7.800,8.800,9.400,10.00)
C_2	MG	VG	MG	VG	MG	(6.600,7.600,8.200,8.800)
C_3	MG	VG	MG	G	VG	(7.000,8.000,8.600,9.200)
C_4	G	G	F	MG	MG	(5.600,6.600,7.400,8.400)
C_5	G	G	MG	VG	MG	(6.600,7.600,8.400,9.200)

Table 7.6: The decision matrix

2nd level indices	Aggregated fuzzy rating (AFR) against individual evaluation indices for alternative suppliers				
	S_1	S_2	S_3	S_4	S_5
C_1	(6.000,7.000,7.600,8.400)	(7.800,8.800,9.400,10.00)	(5.800,6.800,7.800,8.800)	(3.800,4.800,5.400,6.400)	(7.800,8.800,9.400,10.00)
C_2	(5.400,6.400,7.000,8.000)	(6.400,7.400,8.000,8.800)	(5.800,6.800,7.600,8.400)	(7.800,8.800,9.400,10.00)	(6.600,7.600,8.200,8.800)
C_3	(5.800,6.800,7.400,8.400)	(7.800,8.800,9.200,9.600)	(4.600,5.600,6.600,7.600)	(8.200,9.200,9.600,10.00)	(7.000,8.000,8.600,9.200)
C_4	(6.400,7.400,8.200,9.200)	(6.600,7.600,8.400,9.200)	(7.800,8.800,9.200,9.600)	(8.600,9.600,9.800,10.00)	(5.600,6.600,7.400,8.400)
C_5	(6.000,7.000,7.600,8.400)	(5.600,6.600,6.800,7.400)	(4.400,5.400,6.200,7.200)	(7.000,8.000,8.800,9.600)	(6.600,7.600,8.400,9.200)

Table 7.7: The normalized decision matrix

2nd level indices	Normalized fuzzy rating (NFR) against individual evaluation indices for alternative suppliers				
	S_1	S_2	S_3	S_4	S_5
C_1	(0.600,0.700,0.760,0.840)	(0.780,0.880,0.940,1.000)	(0.580,0.680,0.780,0.880)	(0.380,0.480,0.540,0.640)	(0.780,0.880,0.940,1.000)
C_2	(0.540,0.640,0.700,0.800)	(0.640,0.740,0.800,0.880)	(0.580,0.680,0.760,0.840)	(0.780,0.880,0.940,1.000)	(0.660,0.760,0.820,0.880)
C_3	(0.580,0.680,0.740,0.840)	(0.780,0.880,0.920,0.960)	(0.460,0.560,0.660,0.760)	(0.820,0.920,0.960,1.000)	(0.700,0.800,0.860,0.920)
C_4	(0.640,0.740,0.820,0.920)	(0.660,0.760,0.840,0.920)	(0.780,0.880,0.920,0.960)	(0.860,0.960,0.980,1.000)	(0.560,0.660,0.740,0.840)
C_5	(0.524,0.579,0.629,0.733)	(0.595,0.647,0.667,0.786)	(0.611,0.710,0.815,1.000)	(0.458,0.500,0.550,0.629)	(0.478,0.524,0.579,0.667)

Table 7.8: Crisp values for decision matrix and weight of each criterion (under general strategy)

	Criteria				
	C_1	C_2	C_3	C_4	C_5
Weight	0.740	0.872	0.740	0.764	0.848
S1	0.724	0.670	0.710	0.780	0.619
S2	0.898	0.764	0.882	0.794	0.678
S3	0.730	0.714	0.610	0.882	0.788
S4	0.510	0.898	0.922	0.945	0.536
S5	0.898	0.778	0.818	0.700	0.564

Table 7.9: The values of **S**, **R** and **Q** for all suppliers

	Suppliers				
	S1	S2	S3	S4	S5
S	2.500	1.556	2.809	0.740	1.562
R	0.872	0.478	0.848	0.740	0.764
Q	0.92	0.19	0.97	0.33	0.56

Table 7.10: The ranking of the suppliers by **S**, **R** and **Q** in deceasing order

	Ranking order of candidate suppliers (under general strategy)				
	1	2	3	4	5
By S	S4	S2	S5	**S1**	**S3**
By R	**S2**	**S4**	**S5**	S3	S1
By Q	**S2**	**S4**	**S5**	**S1**	**S3**

Table 7.11: The initial DM weight and aggregated weight of criteria under the resiliency strategy

Evaluation indices	Importance weight expressed in linguistic terms					AFW_{Ri}
	DM1	DM2	DM3	DM4	DM5	
R_1	VH	MH	H	H	H	(0.680,0.780,0.820,0.900)
R_2	VH	H	M	M	M	(0.540,0.640,0.660,0.740)
R_3	H	H	H	VH	VH	(0.740,0.840,0.880,0.940)

Table 7.12: Weighted-aggregated rating of alternatives by DM1 for resiliency criteria

	Decision-Maker DM1			$WAFR_{DM1}$
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	
S1	MG	MG	VG	(4.253,5.640,6.387,7.507)
S2	G	G	VG	(5.067,6.587,7.373,8.600)
S3	MG	MG	MG	(3.267,4.520,5.507,6.880)
S4	MP	G	G	(3.440,4.727,5.713,7.100)
S5	VG	G	VG	(5.520,7.107,7.647,8.600)

Table 7.13: Weighted-aggregated rating of alternatives by DM2 for resiliency criteria

	Decision-Maker DM2			$WAFR_{DM2}$
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	
S1	VG	MG	VG	(5.160,6.680,7.207,8.107)
S2	G	VG	G	(4.933,6.453,7.300,8.600)
S3	F	VG	MG	(3.760,5.113,5.620,6.773)
S4	MP	MG	VG	(3.573,4.860,5.567,6.607)
S5	G	MG	G	(4.213,5.600,6.640,8.107)

Table 7.14: Weighted-aggregated rating of alternatives by DM3 for resiliency criteria

	Decision-Maker DM3			$WAFR_{DM3}$
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	
S1	MG	MG	G	(3.760,5.080,6.093,7.507)
S2	MG	G	MG	(3.627,4.947,5.947,7.373)
S3	MP	VG	MG	(3.307,4.593,5.347,6.473)
S4	G	G	G	(4.573,6.027,7.080,8.600)
S5	G	MG	VG	(4.707,6.160,6.933,8.107)

Table 7.15: Weighted-aggregated rating of alternatives by DM4 for resiliency criteria

	Decision-Maker DM4			$WAFR_{DM4}$
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	
S1	MG	MG	F	(3.020,4.240,4.920,6.253)
S2	MG	G	VG	(4.613,6.067,6.827,8.000)
S3	F	MG	MP	(2.300,3.420,4.080,5.340)
S4	G	G	VG	(5.067,6.587,7.373,8.600)
S5	MG	F	VG	(4.073,5.427,5.947,7.013)

Table 7.16: Weighted-aggregated rating of alternatives by DM5 for resiliency criteria

	Decision-Maker DM5			$WAFR_{DM5}$
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	
S1	G	MG	F	(3.473,4.760,5.467,6.853)
S2	G	G	VG	(5.067,6.587,7.373,8.600)
S3	F	G	MP	(2.660,3.847,4.520,5.833)
S4	F	G	MG	(3.400,4.687,5.400,6.773)
S5	MG	F	VG	(4.073,5.427,5.947,7.013)

Table 7.17: Aggregated overall suitability index (OSI_{Ri}) of the alternatives for the resiliency strategy

Criteria	Decision-Makers					Overall aggregated fuzzy rating (AFR_O)	Overall suitability index (OSI_{Ri})
	$WAFR_{DM1}$	$WAFR_{DM2}$	$WAFR_{DM3}$	$WAFR_{DM4}$	$WAFR_{DM5}$		
S1	(4.253,5.640,6.387,7.507)	(5.160,6.680,7.207,8.107)	(3.760,5.080,6.093,7.507)	(3.020,4.240,4.920,6.253)	(3.473,4.760,5.467,6.853)	(3.933,5.280,6.015,7.245)	5.612
S2	(5.067,6.587,7.373,8.600)	(4.933,6.453,7.300,8.600)	(3.627,4.947,5.947,7.373)	(4.613,6.067,6.827,8.000)	(5.067,6.587,7.373,8.600)	(4.661,6.128,6.964,8.235)	6.487
S3	(3.267,4.520,5.507,6.880)	(3.760,5.113,5.620,6.773)	(3.307,4.593,5.347,6.473)	(2.300,3.420,4.080,5.340)	(2.660,3.847,4.520,5.833)	(3.059,4.299,5.015,6.260)	4.658
S4	(3.440,4.727,5.713,7.100)	(3.573,4.860,5.567,6.607)	(4.573,6.027,7.080,8.600)	(5.067,6.587,7.373,8.600)	(3.400,4.687,5.400,6.773)	(4.011,5.377,6.227,7.536)	5.785
S5	(5.520,7.107,7.647,8.600)	(4.213,5.600,6.640,8.107)	(4.707,6.160,6.933,8.107)	(4.073,5.427,5.947,7.013)	(4.073,5.427,5.947,7.013)	(4.517,5.944,6.623,7.7680	6.198

Table 7.18: Supplier Selection Score (SSS_i) (combining selections based on general strategy as well as resiliency strategy)

Suppliers	Q_i (Lower-is-Better)	Q_{Ni}	Ranking order (based on general strategy) Fuzzy VIKOR	OSI_{Ri} (Higher-is-Better)	OSI_{NRi}	Ranking order (based on resiliency strategy
S1	0.92	0.207	4	5.612	0.865	4
S2	0.19	1.000	1	6.487	1.000	1
S3	0.97	0.196	5	4.658	0.718	5
S4	0.33	0.576	2	5.785	0.892	3
S5	0.56	0.339	3	6.198	0.955	2

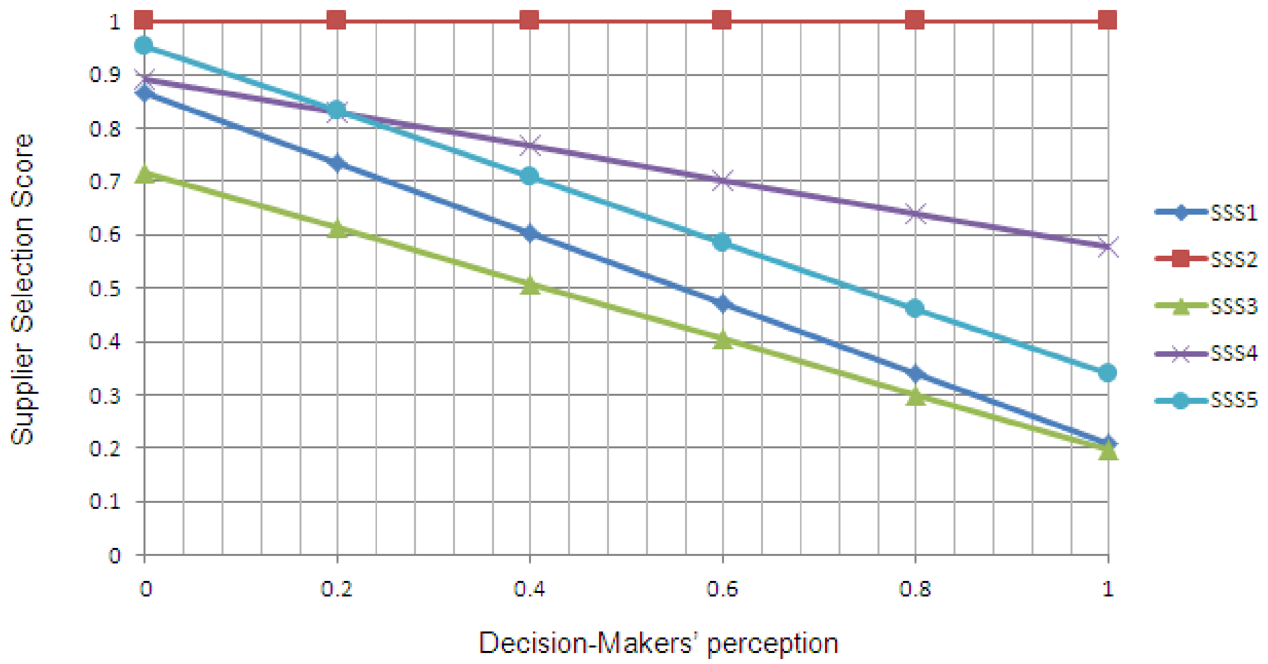

Fig. 7.1: Sensitivity analysis plot (Exploration of Fuzzy-VIKOR)

Table 7.19: Supplier Selection Score (SSS_i) (combining selections based on general strategy as well as resiliency strategy)

Suppliers	CR_i (Higher-is-Better)	CR_{Ni}	Ranking order (based on general strategy) Fuzzy TOPSIS	OSI_{Ri} (Higher-is-Better)	OSI_{NRi}	Ranking order (based on resiliency strategy
S1	0.379	0.512	4	5.612	0.865	4
S2	0.657	0.889	2	6.487	1.000	1
S3	0.312	0.422	5	4.658	0.718	5
S4	0.740	1.000	1	5.785	0.892	3
S5	0.640	0.865	3	6.198	0.955	2

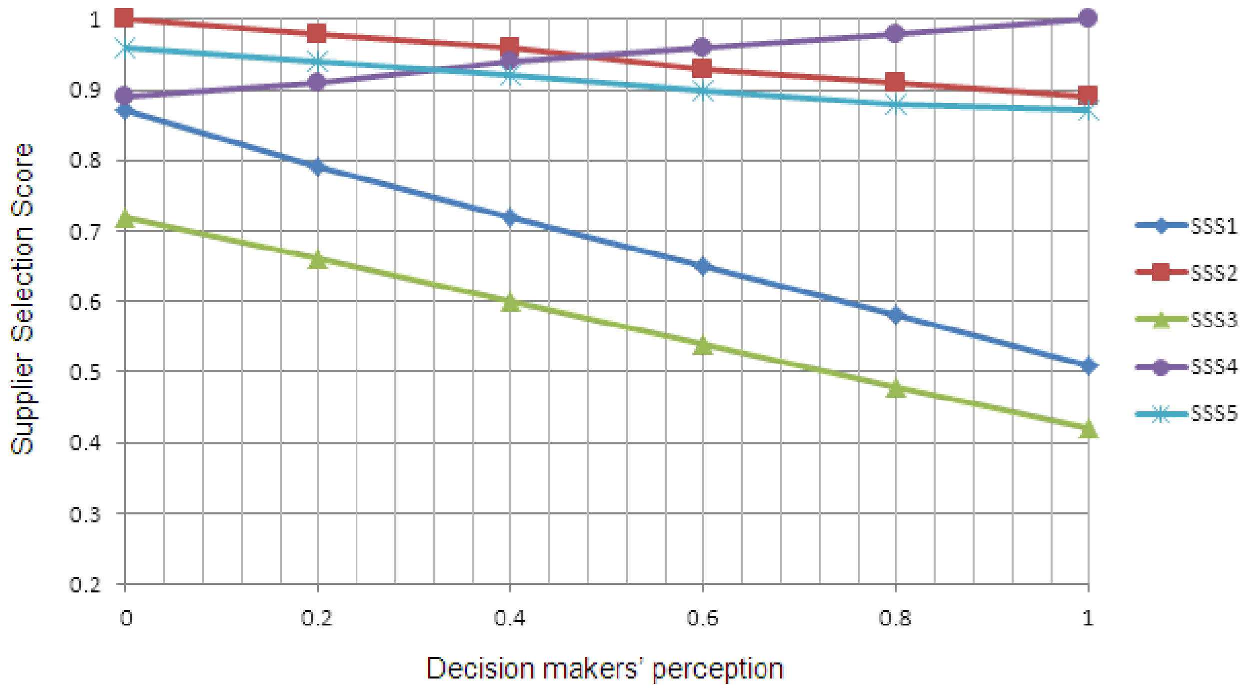

Fig. 7.2: Sensitivity analysis plot (Exploration of Fuzzy-TOPSIS)

CHAPTER 8

SUMMARY AND CONTRIBUTIONS: SCOPE FOR FUTURE WORK

The present work has been summarized below.

Chapter 2 deals with appraisement and benchmarking of overall supply chain performance of candidate case companies. The supply chain has been termed as ‘traditional’ because it has been assumed that performance of the supply chain depends on effective supplying, inbound logistics, core manufacturing, outbound logistics and marketing-sales which are common performance indicators applicable for manufacturing industries. However, due to market globalization, ever-changing customers’ expectations, possibility of supply chain disruption and increased concern for environmental issues etc. necessitates restructuring of traditional supply chain network by introducing modern supply chain philosophies like agility, greenness, flexibility as well as resilience. The purpose is to serve a variety of modern business needs and to ensure competitive advantage in the turbulent market place. Therefore, it is felt that apart from evaluating supply chain performance by considering traditional performance criterions; supply chain needs to be modified in order to achieve different business goals and, thereby, its performance is required to be assessed from the viewpoints of agility, greenness, leagility, flexibility as well as resilience. In **Chapter 2**, a decision making problem has been articulated to benchmark supply chain’s overall performance of candidate companies operating under similar supply chain construct (supplying, inbound logistics, core manufacturing, outbound logistics and marketing-sales). The work explores a 4-level criteria hierarchy (evaluation index system) for appraising overall performance of the supply chain in relation of preferred companies (alternatives). Since, most of the performance indices are subjective in nature; the work explores human judgment of the decision-makers. Subjective human judgment (expert opinion) expressed in linguistic terms has been analyzed through systematic exploration of grey numbers set theory as well as fuzzy set theory, respectively. Two decision-making approaches: (i) Grey-MOORA and (ii) Fuzzy-MOORA have been applied towards evaluating performance ranking order of candidate industries and selecting the best one.

Performance appraisement and benchmarking of green supply chain has been attempted in **Chapter 3**. Two empirical case studies have been reported here. The first one explores IVFN-TOPSIS towards ‘green’ performance benchmarking of candidate icompanies that are following similar green initiatives (green supply chain construct). An integrated 2-level criteria hierarchy (consisting of green supply chain performance measures and metrics) has been developed here. Green purchasing, green marketing, green manufacturing, green design, green packaging and green recycling have been considered as major performance measures (main indices) for the green supply chain. An Interval-Valued Fuzzy Numbers (IVFNs) set theory coupled with the

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) has been explored to deal with subjective evaluation information (as provided by the decision-makers) towards determining appropriate ranking order of the preferred candidate companies (alternatives) from green performance perspective of their supply chain network.

The second part of this chapter articulates another decision making scenario in which candidate companies have been ranked based on their 'green' performance by considering the following performance indices in relation to the green supply chain: organizational commitment, eco-design, green supply chain process, social performance and sustainable performance. The work explores generalized triangular fuzzy numbers set theory combined with grey relation theory (fuzzy-grey relation analysis) to facilitate performance benchmarking of green supply chain of alternative industries.

In **Chapter 4** a fuzzy based Multi-Level Multi-Criterion Decision Making (MLMCDM) approach has been attempted towards evaluation and selection of potential suppliers in green supply chain. In this work, subjectivity associated with ill-defined (vague) green performance indices has been tackled through exploration of fuzzy numbers set theory. The aforesaid fuzzy embedded MLMCDM module is capable of dealing with subjective (qualitative) as well as objective (quantitative) data in order to compute a unique ranking score. The specialty of this approach is the exploration of multi-layered criteria hierarchy in which each main criterion is divided into a number of sub-criteria, each sub-criterion is further divided into some sub-sub-criteria and so on. Supplier ranking is made by comparing ranking scores of candidate suppliers. An empirical case study has been illustrated here. In this part of work, an integrated criteria hierarchy has been adapted by considering subjective performance indices of green suppliers. It is basically a 2-level criteria hierarchy consisting of 1^{st} level main indices: Management competencies, Green image, Design for environment, Environmental management systems, and Environmental competencies. Each 1^{st} level index has been followed by 2^{nd} level sub-indices. The ranking order of green suppliers obtained from FMLMCDM approach has compared to that of fuzzy-TOPSIS.

Chapter 5 exhibits results of an industrial case study which aims to evaluate a quantitative metric for supply chain flexibility. The work conceptualizes supply chain flexibility depending upon five major dimensions: supply network flexibility, operations system flexibility, logistics process flexibility, information systems flexibility and organizational design flexibility. A 2-level integrated criteria hierarchy consisting of aforesaid 1^{st} level main indices (followed by 2^{nd} level sub-indices) has been adapted as an evaluation platform for estimating supply chain flexibility at an organizational context. Subjective evaluation information as provided by the expert group has been transformed into generalized trapezoidal fuzzy numbers set. Then, by applying fuzzy mathematics (operational rules), overall supply chain flexibility has been assessed in terms of fuzzy score. The theory of fuzzy numbers ranking (by considering crisp score through 'Incentre of Centroid' method) and the concept of Fuzzy Performance Importance Index (FPII) have been fruitfully utilized to identify ill-performing supply chain entities which require future improvement to enrich supply chain's overall flexibility.

Chapter 6 represents a case research towards evaluating supply chain's resilience performance. A 3-level criteria hierarchy has been developed here highlighting various indices (performance indicators) for assessing supply chain resilience. Supply chain reengineering, supply chain collaboration, supply chain risk management culture and supply chain agility have been considered as major dimensions (1^{st} level indices) for supply chain resilience. Each 1^{st} level index has been classified into several sub-indices (at 2^{nd} level); and, each 2^{nd} level sub-index has further been followed by sub-sub-indices (at 3^{rd} level). Aforesaid evaluation index system (in the form of a questionnaire) has been utilized to gather expert opinion in relation to priority weight as well as appropriateness rating against resilient performance evaluation indices of the said case company. Expert judgments (expressed in linguistic terms) have been converted into appropriate fuzzy values. By exploring fuzzy operational rules, a unique resilient performance metric has been determined. The work also extends to identify ill-performing supply chain entities (barriers of supply chain resiliency) by utilizing the concept of FPII and the theory of fuzzy numbers ranking through '*Maximizing Set and Minimizing Set*' approach. In this work, different risk-bearing attitudes of the decision-makers' have also been considered.

Chapter 7 deals with resilient supplier selection in fuzzy environment. A list of supplier selection criterions have been selected based on suppliers' general strategy as well as resiliency strategy. Under general strategy, product quality, reliability of the product, functionality of the product, extent of customers' satisfaction and product price have been considered; whereas, the following criterions: investment in capacity buffers, responsiveness and capacity for holding strategic inventory stocks for crises have been chosen as key performance criterions in selecting a resilient supplier. In this work, subjective evaluation information as provided by the expert group has been transformed into appropriate generalized trapezoidal fuzzy numbers set. Initially, a decision making approach based on Fuzzy-VIKOR has been adapted to compute a VIKOR INDEX (Q) against each alternative in order to rank candidate suppliers based on

general strategy only. An Overall Suitability Index (OSI) has been computed based on which alternative suppliers could be ranked by considering resiliency strategy. Sensitivity analysis has been carried out to exhibit the trade-off between general selection criteria and resiliency criteria, where, a 'Supplier Selection Score' (SSS) has been measured for each of the candidate suppliers. In computing SSS, decision-makers' risk bearing attitude has been taken under consideration. Three kinds of decision-makers' like optimistic, neutral/moderate as well as pessimistic has been considered. Sensitivity analysis reflects how choice of potential supplier changes with respect to change in risk bearing attitude of the decision-makers.
Aforesaid work has been extended to examine application potential of Fuzzy-TOPSIS in comparison with Fuzzy-VIKOR. Instead of computing VIKOR INDEX (Q) (as obtained in Fuzzy-VIKOR), the work explores Fuzzy-TOPSIS to compute a unique performance index (Closeness Ratio, CR) comparing which suppliers could be ranked under general strategy. Then, an Overall Suitability Index (OSI) has been derived to select appropriate suppliers based on resiliency strategy. Finally, by combining CR and OSI, a 'Supplier Selection Score' (SSS) has been computed to show the trade-off between general as well resiliency criteria in selecting the most appropriate supplier. Results show that Fuzzy-VIKOR and Fuzzy-TOPSIS are compliment to each other providing compatible results.

Contributions of the present work have been pointed out below.

- Exploration of Grey-MOORA as well as Fuzzy-MOORA towards appraisement and benchmarking of supply chain (traditional) performance of candidate companies operating under similar supply chain construct (criteria-hierarchy). Grey numbers/fuzzy numbers set theory has been utilized to tackle inherent vagueness, ambiguity, imprecision as well as inconsistency in subjective evaluation information provided by the decision-makers.

- Exploration of IVFN-TOPSIS and fuzzy-grey relation method towards benchmarking of green supply chain performance of alternative companies operating under similar green initiatives (green supply chain constructs).

- Exploration of a fuzzy based Multi-Level Multi-Criteria Decision Making (MLMCDM) module towards evaluation and selection of potential suppliers in green supply chain. Results (ranking order of candidate suppliers) obtained on exploration of FMLMCDM approach has been compared to that of Fuzzy-TOPSIS. Good agreement has been observed between the two. This validates application potential of aforesaid FMLMCDM approach in the context of green suppliers' selection.

- Development of a fuzzy based decision support system to evaluate a quantitative performance metric for supply chain flexibility. The work utilizes the concept of Fuzzy Performance Importance Index (FPII) and the theory of fuzzy numbers ranking by '*Incentre of Centroid*' method in order to identify ill-performing supply chain areas (known as barriers of supply chain flexibility) which require future attention to improve overall supply chain flexibility.

- Development of a fuzzy based decision making module to evaluate a unique performance metric for supply chain resilience. The concept of FPII and the theory of fuzzy numbers ranking by '*Maximizing Set and Minimizing Set*' have been explored here to identify various supply chain barriers which need future improvement to boost up overall supply chain resilience.

- Exploration of a fuzzy based decision support system towards evaluation and selection of resilient suppliers. Application potential of fuzzy-VIKOR has been compared to that of Fuzzy-TOPSIS. A trade-off between suppliers' general strategy as well as resiliency strategy has been examined through sensitivity analysis. An overall Supplier Selection Score (SSS) has been introduced by combining supplier performance scores for general as well as resiliency strategies both. Influence of decision-makers' risk bearing attitude has been examined in selecting potential supplier in resilient supply chain.

Limitations of the present work have been highlighted below.

- Based on various performance indices, integrated criteria-hierarchies have been adapted in order to appraise as well as benchmark supply chain's overall performance. The criteria-hierarchies thus selected consist of multi-level performance indicators. Main-indices have been classified into various sub-indices followed by sub-sub-indices and so on. The hierarchy (also called evaluation index system) has been utilized as a reference for collection of expert judgment in relation to appropriateness rating as well as priority weight of various performance indices. A variety of criteria-hierarchies have been conceptualized in view of assessing supply chain performance from different perspectives (traditional, green, flexible and resilient supply chain). For performance benchmarking, it has been assumed that the preferred candidate industries operate under similar supply chain construct. The criteria-hierarchies adapted here have been assumed generic irrespective of specific product/service.

- In fuzzy based decision support systems (Fuzzy-TOPSIS, Fuzzy-MOORA, Fuzzy-Grey Relation Method), linguistic human judgment needs to be translated into appropriate fuzzy numbers. It is assumed that the linguistic term set (using which decision-makers express their subjective preference) and corresponding fuzzy numbers representation (fuzzy numbers scale against linguistic term set) is predefined and set at the top-managerial level of the organization. The choice of the type of fuzzy number (generalized/ Interval-Valued/ Intuitionistic) and corresponding fuzzy membership function should also be set by the managerial level and be accepted by the experts. It is worth of investigating which fuzzy number (specific type) could provide the most reliable result.

- Decision support systems dealing with subjective evaluation information of candidate alternatives require active participation of a group of decision-makers (experts). However, it is assumed that the selection of expert panel members as well as the number of experts to participate in decision-making, to be decided by the industry management. The optimal number of decision-makers to provide the most appropriate decision outcome is completely unknown.

- A variety of performance appraisement modules (in relation of supply chain as well as supplier performance) have been demonstrated in this work; however, reliability testing for these decision support modules has not been attempted.

- In course of assessing supply chain flexibility as well as resilience performance, ill-performing supply chain entities have been identified which require future improvement to enhance supply chain's overall performance. However, possible action plans in regards of improving those supply chain barriers have not been proposed here.

- The dissertation deals with different decision support systems to be operated under fuzzy/grey environment in order to appraise supply chain's overall performance as well as to facilitate potential supplier selection. However, it does not emphasize to compare relative efficacies of those models. It is indeed difficult to defend this issue. Each decision support system works under its own principle. The method of normalization varies from one another. Some decision support systems explore objective (quantitative) criteria weight rather than subjective weight. Few fuzzy based decision support systems explore defuzzification (instead of using fuzzy operational rules) to compute representative crisp score to be utilized for decision-making. There exists a variety of defuzzification techniques and it is very difficult to select the most accurate one. If different decision support systems are applied on a same problem; there is no guaranty that alternative ranking order will appear similar. In this context, the application of '*Theory of Dominance*' deserves mention. It is, therefore, assumed that the choice of a particular decision support system is solely a managerial concern.

Work can be extended further in order to re-examine aforesaid issues.

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Journal Publications

Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, *Green Supply Chain Performance Benchmarking using Integrated IVFN-TOPSIS Methodology,* **International Journal of Process Management and Benchmarking**, 3(4) (2013): 511-551, Inderscience Publishers, Switzerland.

Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, *Use of IVFNs and MULTIMOORA Method for supply chain performance measurement, benchmarking and decision-making: an empirical study*, **International Journal of Business Excellence**, 7(2) (2014): 237-280, Inderscience Publishers, Switzerland.

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Anoop Kumar Sahu, Santosh Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, *Supply Chain Flexibility Assessment and Decision Making: A Fuzzy Intelligent Approach*, **International Journal of Business Excellence**, Inderscience Publishers, Switzerland. **(Accepted)**

Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, *Green Supply Chain Performance Appraisement and Benchmarking using Fuzzy Grey Relation Method*, **International Journal of Business Information Systems**, Inderscience Publishers, Switzerland. **(Accepted)**

Anoop Kumar Sahu**, Saurav Datta, Siba Sankar Mahapatra, *Evaluation and Selection of Resilient Suppliers in Fuzzy Environment: Exploration of Fuzzy-VIKOR*, **Benchmarking: an International Journal**, Emerald Group Publishing, UK. **(Accepted)**

Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, *Evaluation and Selection of Suppliers Considering Green Perspectives: Comparative Analysis on Application of FMLMCDM and Fuzzy-TOPSIS*, **Benchmarking: an International Journal**, Emerald Group Publishing, UK. **(Accepted)**

Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra *Evaluation of Performance Index in Resilient Supply Chain: A Fuzzy Based Approach*, **Benchmarking: an International Journal**, Emerald Group Publishing, UK. **(Accepted)**

Publications in Proceedings of International/ National Conferences

Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, *Decision-Making in Supply Chain Performance Management using Fuzzy based MULTIMOORA Approach*, International Conference on Computational Intelligence and Advanced Manufacturing Research (ICCIAMR-2013), 5-6 April 2013, organized by Department of Mechanical Engineering, VELS University, Chennai-600117.

Anoop Kumar Sahu, Saurav Datta and Siba Sankar Mahapatra, *Supply Chain Performance Measurement, appraisement by Grey-MULTIMOORA: An Empirical Study*, 2nd International Conference on Industrial Engineering, Theme: Modern Trends in Industrial Engineering, November 20-22, 2013, organized by Department of Mechanical Engineering, S.V. National Institute of Technology, Surat, In Association with Indian Institution of Industrial Engineering (IIIE), NHQ-Mumbai.

Aditya, Santosh Kumar Sahu, **Anoop Kumar Sahu**, Saurav Datta, Siba Sankar Mahapatra, *A Decision Support System towards Suppliers' Selection in Resilient Supply Chain: Exploration of Fuzzy-TOPSIS*, International Conference on Management of Marketing, Banking, Business and Finance for Sustainable Economy (MBFSE- 2014), organized by Social Welfare Foundation during 5-6 July, 2014, at Jawaharlal Nehru University, New Delhi.

Glossary

AHP: Analytic Hierarchy Process

ANP: Analytic Network Process

BOCR: Benefits, Opportunities, Costs and Risks

CBR: Case-Based Reasoning

CDM: Collaborative Decision Making

COA: Center of Area

COG: Center of Gravity

CSS: Combined Supplier Score

DEA: Data Envelopment Analysis

DEMATEL: Decision Making Trial and Evaluation Laboratory

DMs: Decision-Makers

DSS: Decision Support System

ECP: Supporting Environmentally Conscious Purchasing

FAHP: Fuzzy Analytic Hierarchy Process

FMADM: Fuzzy Multi-Attribute Decision Making

FMLMCDM: Fuzzy based Multi-Level Multi-Criteria Decision Making

FPI: Fuzzy Performance Index

FPII: Fuzzy Performance Importance Index

GP: Goal Programming

GRA: Grey Relational Analysis

GrBSc: Green-Balanced Scorecard

GSC: Green Supply Chain

GSCM: Green Supply Chain Management

IFS: Intuitionistic Fuzzy Set

IFWA: Intuitionistic Fuzzy Weighted Average

ITAE: Integral of the Time Absolute Error

IVFN: Interval-Valued Fuzzy Number

LARG: Lean, Agile, Resilient, Green

LP: Linear Programming

MAUT: Multi-Attribute Utility Theory

MCDM: Multi-Criteria Decision Making

MCGDM: Multi-Criteria Group Decision Making

MOMILP: Multi-Objective Mixed Integer Linear Programming

MOORA: Multi-Objective Optimization by Ratio Analysis

MOPLP: Multi-Objective Possibilistic Linear Programming

MULTIMOORA: MOORA plus the full multiplicative form

NIS: Negative Ideal Solution (Anti-Ideal Solution)

OFM: Objective Factor Measure

OWA: Ordered Weighted Average

PIS: Positive Ideal Solution

PLP: Possibilistic Linear Programming

PMS: Performance Measurement System

QFD: Quality Function Deployment

SC: Supply Chain

SCF: Supply Chain Flexibility

SCOR: Supply Chain Operations Reference

SEM: Structural Equation Modeling

SFM: Subjective Factor Measures

SMART: Simple Multi-Attribute Rating Technique

SMEs: Small and Medium Enterprises

SP: Stochastic Programming

SWOT: Strengths, Weaknesses, Opportunities and Threats

TOPSIS: Technique for Order Preference by Similarity to Ideal Solution

VIKOR: *VIse Kriterijumska Optimizacija I Kompromisno Resenje*

VSP: Vendor Selection Problem

Resume

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